US011010968B2

(12) United States Patent
Hare et al.

(10) Patent No.: US 11,010,968 B2
(45) Date of Patent: *May 18, 2021

(54) **AUTOMATED THREE DIMENSIONAL MODEL GENERATION**

(71) Applicant: **Snap Inc.**, Santa Monica, CA (US)

(72) Inventors: **Samuel Edward Hare**, Los Angeles, CA (US); **Ebony James Charlton**, Santa Monica, CA (US); **Andrew James McPhee**, Culver City, CA (US); **Michael John Evans**, Venice, CA (US)

(73) Assignee: **Snap Inc.**, Santa Monica, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/674,892**

(22) Filed: **Nov. 5, 2019**

(65) **Prior Publication Data**

US 2020/0066037 A1 Feb. 27, 2020

Related U.S. Application Data

(63) Continuation of application No. 16/226,108, filed on Dec. 19, 2018, now Pat. No. 10,515,480, which is a (Continued)

(51) **Int. Cl.**

G06T 17/20	(2006.01)
G06K 9/00	(2006.01)
G06T 7/55	(2017.01)

(52) **U.S. Cl.**

CPC ***G06T 17/20*** (2013.01); ***G06K 9/00201*** (2013.01); ***G06K 9/00261*** (2013.01);
(Continued)

(58) **Field of Classification Search**

CPC G06T 17/00–30; G06T 7/55; G06T 17/20; G06T 2200/08; G06T 2200/24;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,038,295	A	3/2000	Mattes
6,980,909	B2	12/2005	Root et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CA	2887596	A1	7/2015
CN	1710613	A	12/2005

(Continued)

OTHER PUBLICATIONS

NPL Video Titled "Glasses.com App for iPad", Published Jul. 8, 2013; available for viewing at: https://www.youtube.com/watch?v=quUJ5ag3a-g; select screenshots included. (Year: 2013).*

(Continued)

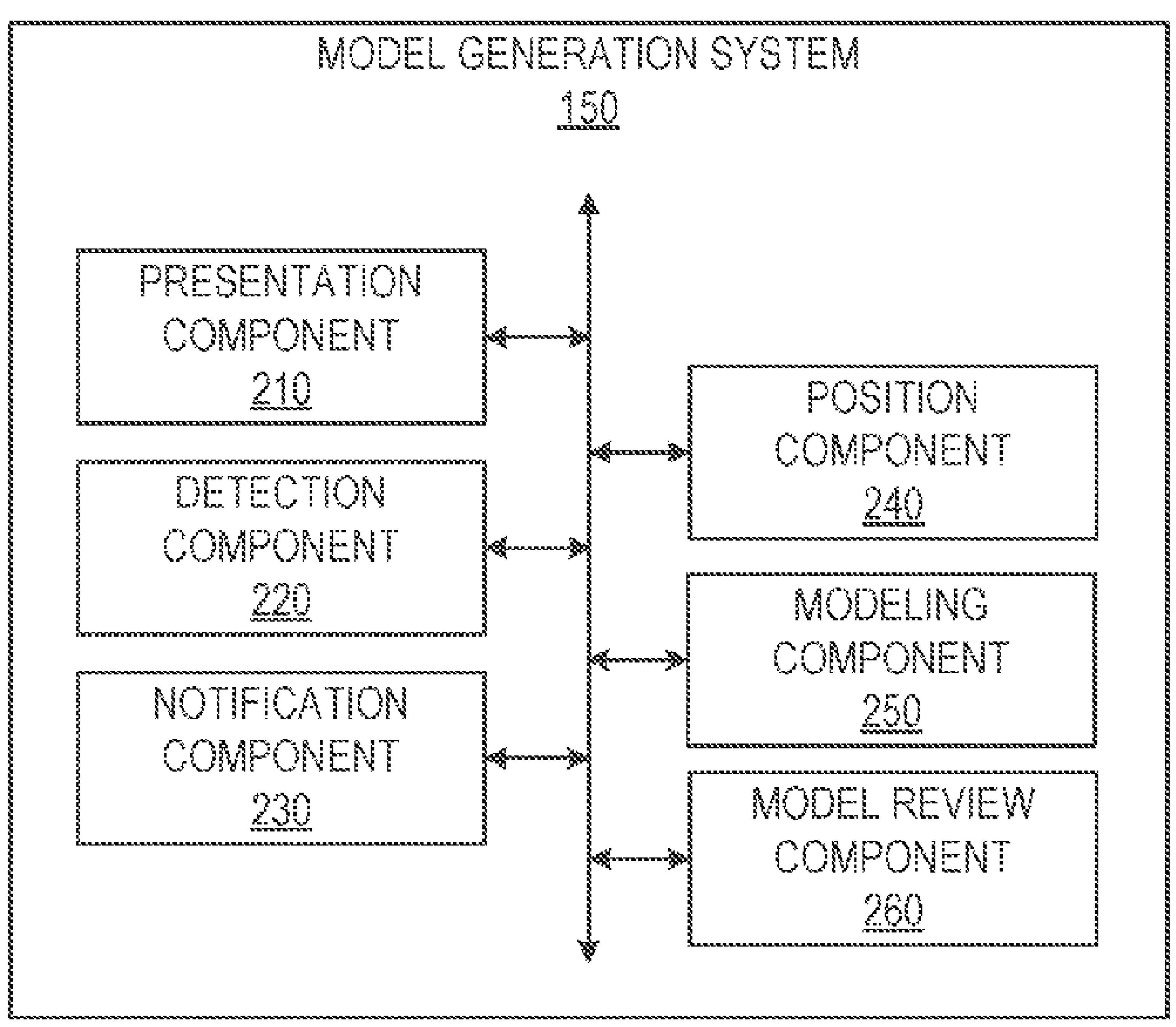
Primary Examiner — Daniel F Hajnik

(74) *Attorney, Agent, or Firm* — Schwegman Lundberg & Woessner, P.A.

(57) **ABSTRACT**

In various example embodiments, a system and methods are presented for generation and manipulation of three dimensional (3D) models. The system and methods cause presentation of an interface frame encompassing a field of view of an image capture device. The systems and methods detect an object of interest within the interface frame, generate a movement instruction with respect to the object of interest, and detect a first change in position and a second change in position of the object of interest. The systems and methods generate a 3D model of the object of interest based on the first change in position and the second change in position.

20 Claims, 24 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/816,795, filed on Nov. 17, 2017, now Pat. No. 10,198,859, which is a continuation of application No. 15/080,367, filed on Mar. 24, 2016, now Pat. No. 9,852,543.

(60) Provisional application No. 62/139,009, filed on Mar. 27, 2015.

(52) **U.S. Cl.**
CPC ***G06K 9/00912*** (2013.01); ***G06T 7/55*** (2017.01); *G06T 2200/08* (2013.01); *G06T 2200/24* (2013.01); *G06T 2207/30201* (2013.01)

(58) **Field of Classification Search**
CPC G06T 2207/30201; G06K 9/00201; G06K 9/00261; G06K 9/00912
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,103,211	B1	9/2006	Medioni et al.		
7,173,651	B1	2/2007	Knowles		
7,411,493	B2	8/2008	Smith		
7,535,890	B2	5/2009	Rojas		
8,131,597	B2	3/2012	Hudetz		
8,199,747	B2	6/2012	Rojas et al.		
8,332,475	B2	12/2012	Rosen et al.		
8,718,333	B2	5/2014	Wolf et al.		
8,724,622	B2	5/2014	Rojas		
8,874,677	B2	10/2014	Rosen et al.		
8,909,679	B2	12/2014	Root et al.		
8,995,433	B2	3/2015	Rojas		
9,040,574	B2	5/2015	Wang et al.		
9,055,416	B2	6/2015	Rosen et al.		
9,100,806	B2	8/2015	Rosen et al.		
9,100,807	B2	8/2015	Rosen et al.		
9,191,776	B2	11/2015	Root et al.		
9,204,252	B2	12/2015	Root et al.		
9,443,227	B2	9/2016	Evans et al.		
9,489,661	B2	11/2016	Evans et al.		
9,491,134	B2	11/2016	Rosen et al.		
9,852,543	B2	12/2017	Hare et al.		
10,198,859	B2	2/2019	Hare et al.		
10,515,480	B1	12/2019	Hare et al.		
2002/0012454	A1	1/2002	Liu et al.		
2008/0279425	A1*	11/2008	Tang	G06K 9/00221	382/118
2011/0202598	A1	8/2011	Evans et al.		
2012/0075496	A1	3/2012	Akifusa et al.		
2012/0209924	A1	8/2012	Evans et al.		
2013/0101182	A1*	4/2013	Frischholz	G06K 9/00899	382/118
2013/0286161	A1	10/2013	Lv et al.		
2013/0329014	A1	12/2013	Obata		
2013/0335416	A1	12/2013	Coon et al.		
2014/0129935	A1	5/2014	Ovadia Nahon		
2015/0229838	A1*	8/2015	Hakim	H04N 5/23293	348/333.02
2015/0279083	A1*	10/2015	Pradeep	G06T 17/00	345/419
2015/0364158	A1	12/2015	Gupte		
2016/0024325	A1	1/2016	Li		
2016/0284123	A1	9/2016	Hare et al.		
2018/0075651	A1	3/2018	Hare et al.		

FOREIGN PATENT DOCUMENTS

CN	103167270	A	6/2013
CN	108012559	A	5/2018
JP	2012074878	A	4/2012
KR	20130036430	A	4/2013
KR	20140000315	A	1/2014
KR	1020140000315	A	1/2014
KR	102003813	B1	7/2019
WO	WO-2016160606	A1	10/2016

OTHER PUBLICATIONS

NPL Video Titled: "Scan yourself into virtual worlds with Seene" May 5, 2015; https://www.youtube.com/watch?v=gLMOpt5invA; select screenshots included. (Year: 2015).*

NPL Video Titled: "3D Face scan with kinect—SWoOZ 1.0", published Jan. 2015, available at: https://www.youtube.com/watch?v=sA8i7f6BFi8; select screenshots included. (Year: 2015).*

"U.S. Appl. No. 15/080,367, Non Final Office Action dated May 2, 2017", 19 pgs.

"U.S. Appl. No. 15/080,367, Notice of Allowance dated Aug. 18, 2017", 5 pgs.

"U.S. Appl. No. 15/080,367, Response filed Aug. 2, 2017 to Non Final Office Action dated May 2, 2017", 19 pgs.

"U.S. Appl. No. 15/816,795, Corrected Notice of Allowability dated Jan. 2, 2019", 2 pgs.

"U.S. Appl. No. 15/816,795, Final Office Action dated May 23, 2018", 27 pgs.

"U.S. Appl. No. 15/816,795, Non Final Office Action dated Jan. 10, 2018", 21 pgs.

"U.S. Appl. No. 15/816,795, Notice of Allowance dated Sep. 28, 2018", 10 pgs.

"U.S. Appl. No. 15/816,795, Response filed Apr. 11, 2018 to Non Final Office Action dated Jan. 10, 2018", 14 pgs.

"U.S. Appl. No. 15/816,795, Response filed Aug. 31, 2018 to Final Office Action dated May 23, 2018", 13 pgs.

"U.S. Appl. No. 16/226,108, Advisory Action dated Jul. 30, 2019", 3 pgs.

"U.S. Appl. No. 16/226,108, Final Office Action dated Jun. 12, 2019", 32 pgs.

"U.S. Appl. No. 16/226,108, Non Final Office Action dated Feb. 7, 2019", 27 pgs.

"U.S. Appl. No. 16/226,108, Notice of Allowance dated Aug. 13, 2019", 5 pgs.

"U.S. Appl. No. 16/226,108, Response filed Apr. 10, 2019 to Non Final Office Action dated Feb. 7, 2019", 12 pgs.

"U.S. Appl. No. 16/226,108, Response filed Jul. 12, 2019 to Final Office Action dated Jun. 12, 2019", 9 pgs.

"European Application Serial No. 16718537.0, Response filed May 17, 2018 to Communication pursuant to Rules 161(1) and 162 EPC dated Nov. 7, 2017", w/ English Claims, 179 pgs.

"International Application Serial No. PCT/US2016/024325, International Preliminary Report on Patentability dated Oct. 12, 2017", 11 pgs.

"International Application Serial No. PCT/US2016/024325, International Search Report dated Jun. 16, 2016", 6 pgs.

"International Application Serial No. PCT/US2016/024325, Written Opinion dated Jun. 16, 2016", 10 pgs.

"Korean Application Serial No. 10-2017-7031117, Notice of Preliminary Rejection dated Oct. 16, 2018", w/ English Translation, 19 pgs.

"Korean Application Serial No. 10-2017-7031117, Response filed Dec. 14, 2018 to Notice of Preliminary Rejection dated Oct. 16, 2018", w/ English Claims, 29 pgs.

"Korean Application Serial No. 10-2019-7021230, Notice of Preliminary Rejection dated Nov. 12, 2019", w/ English Translation, 18 pgs.

"Korean Application Serial No. 10-2019-7021230, Response filed Jan. 13, 2020 to Notice of Preliminary Rejection dated Nov. 12, 2019", w/ English Claims, 26 pgs.

Garrido, Pablo, et al., "Reconstructing Detailed Dynamic Face Geometry from Monocular Video", ACM Transactions on Graphics (TOG)—Proceedings of ACM SIGGRAPH Asia, 32(6), (Nov. 2013), 10 pgs.

Leyden, John, "This SMS will self-destruct in 40 seconds", [Online] Retrieved from the Internet: <URL: http://www.theregister.co.uk/2005/12/12/stealthtext/>, (Dec. 12, 2005), 1 pg.

(56) **References Cited**

OTHER PUBLICATIONS

Tanskanen, et al., "Live Metric 3D Reconstruction on Mobile Phone", IEEE International Conference on Computer Vision, (Dec. 2013), 8 pgs.
"Chinese Application Serial No. 201680030189.6, Office Action dated Sep. 15, 2020", w/ English Translation, 16 pgs.
"European Application Serial No. 16718537.0, Communication Pursuant to Article 94(3) EPC dated Oct. 20, 2020", 4 pgs.
Duan, Hong, et al., "Tracking Facial Feature Points Using Kanade-Lucas-Tomasi Approach", Computer Aided Design and Graphics Journal of Science, vol. 16, No. 3, (Mar. 31, 2004), 279-284.
Misawa, T, et al., "Automatic Face Tracking and Model Match-Move in Video Sequence using 3D Face Model", IEEE International Conference on Multimedia Expo, (2001), 349-351.

* cited by examiner

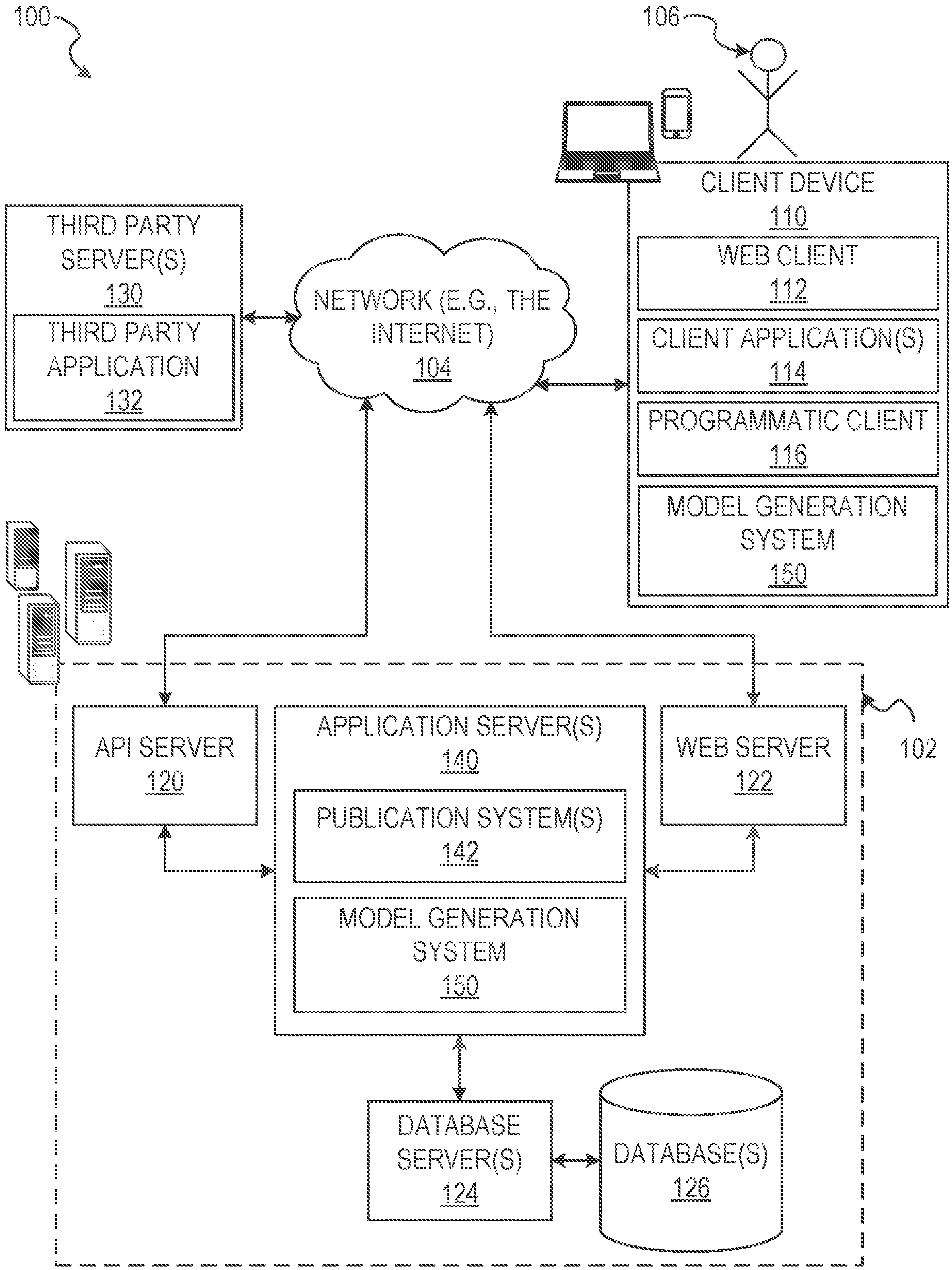

100
106
THIRD PARTY SERVER(S) 130
THIRD PARTY APPLICATION 132
NETWORK (E.G., THE INTERNET) 104
CLIENT DEVICE 110
WEB CLIENT 112
CLIENT APPLICATION(S) 114
PROGRAMMATIC CLIENT 116
MODEL GENERATION SYSTEM 150
API SERVER 120
APPLICATION SERVER(S) 140
PUBLICATION SYSTEM(S) 142
MODEL GENERATION SYSTEM 150
WEB SERVER 122
102
DATABASE SERVER(S) 124
DATABASE(S) 126

FIG. 1

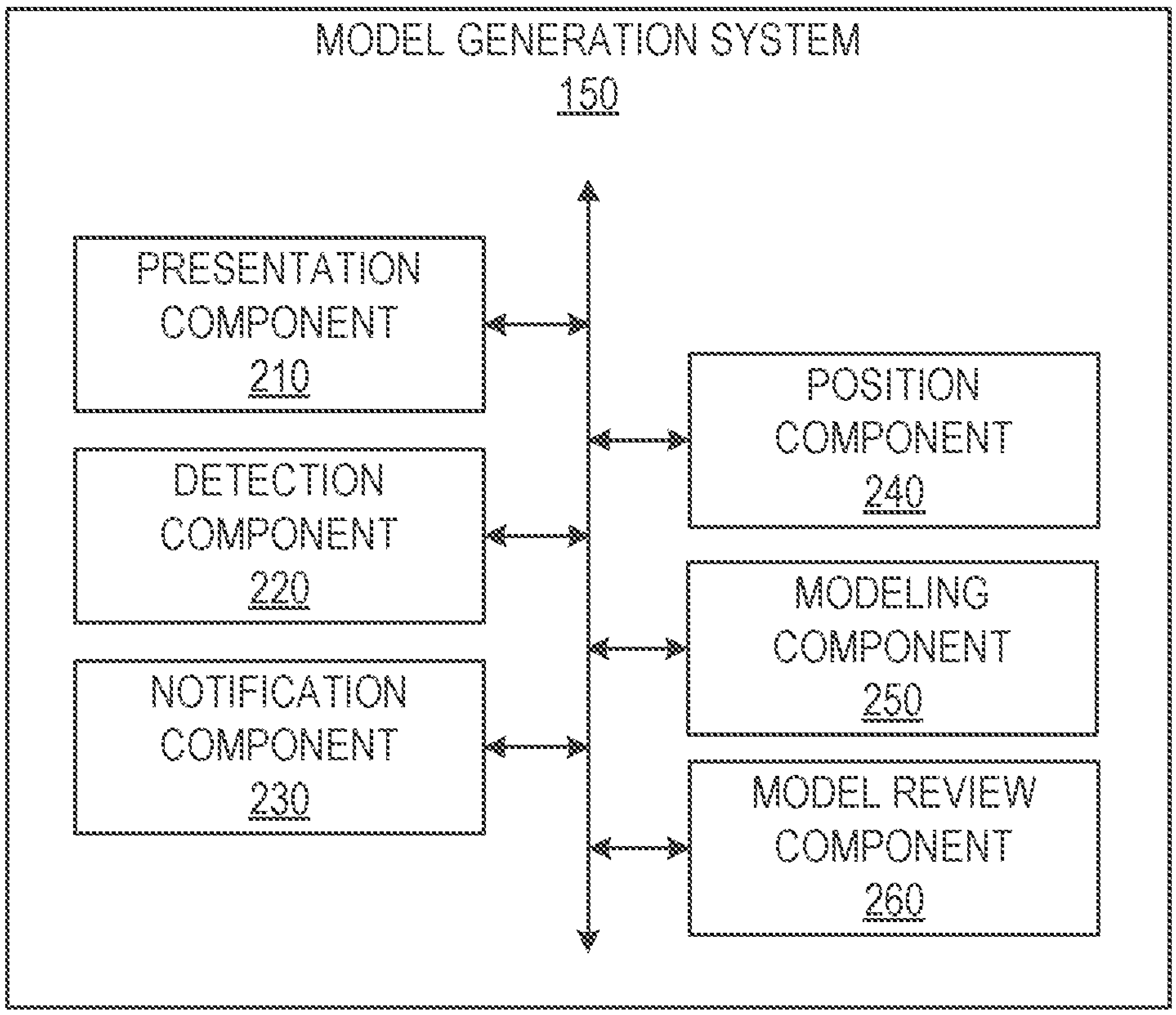

MODEL GENERATION SYSTEM
150
PRESENTATION COMPONENT
210
DETECTION COMPONENT
220
NOTIFICATION COMPONENT
230
POSITION COMPONENT
240
MODELING COMPONENT
250
MODEL REVIEW COMPONENT
260

FIG. 2

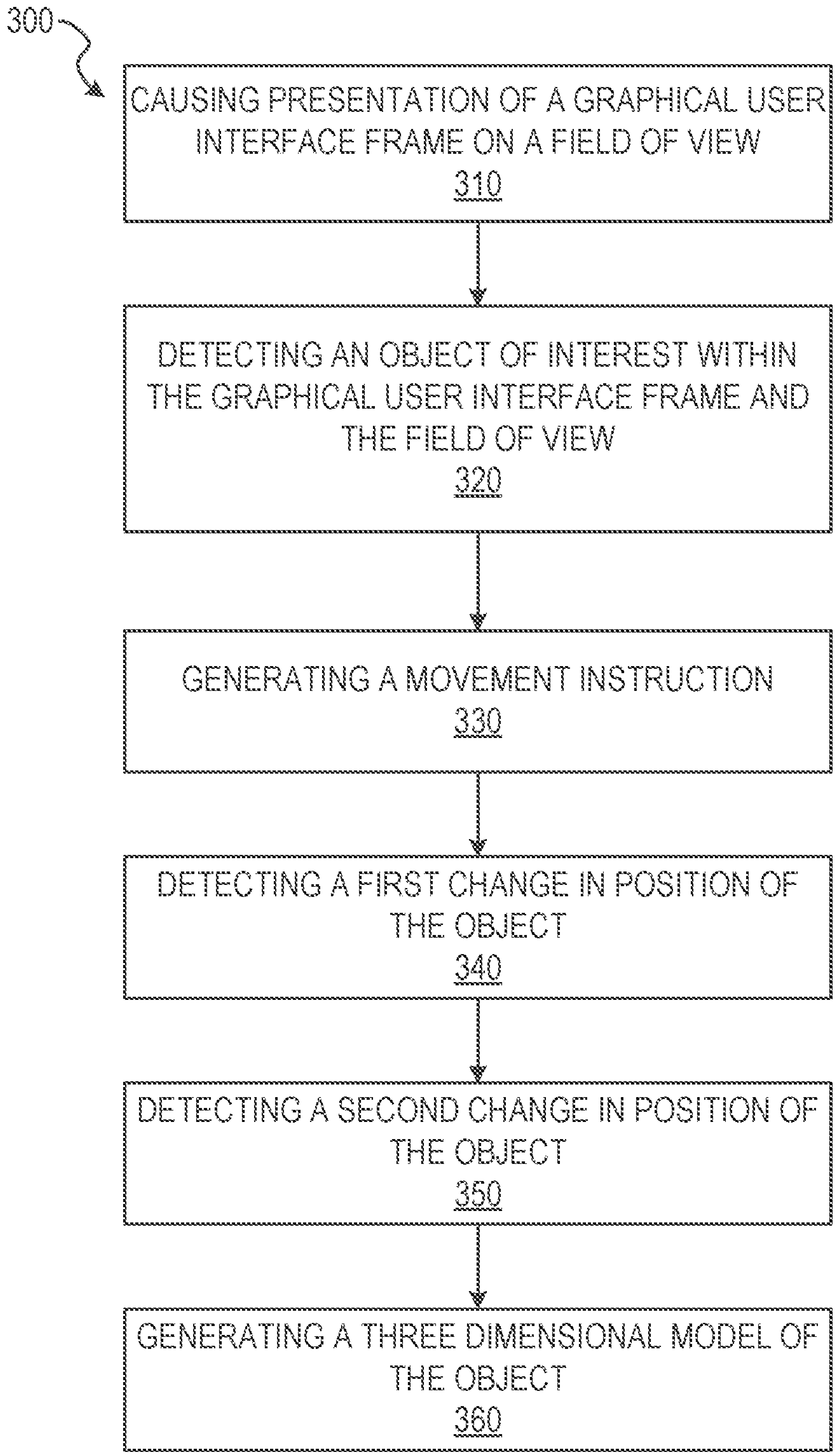

300
CAUSING PRESENTATION OF A GRAPHICAL USER INTERFACE FRAME ON A FIELD OF VIEW
310
DETECTING AN OBJECT OF INTEREST WITHIN THE GRAPHICAL USER INTERFACE FRAME AND THE FIELD OF VIEW
320
GENERATING A MOVEMENT INSTRUCTION
330
DETECTING A FIRST CHANGE IN POSITION OF THE OBJECT
340
DETECTING A SECOND CHANGE IN POSITION OF THE OBJECT
350
GENERATING A THREE DIMENSIONAL MODEL OF THE OBJECT
360

FIG. 3

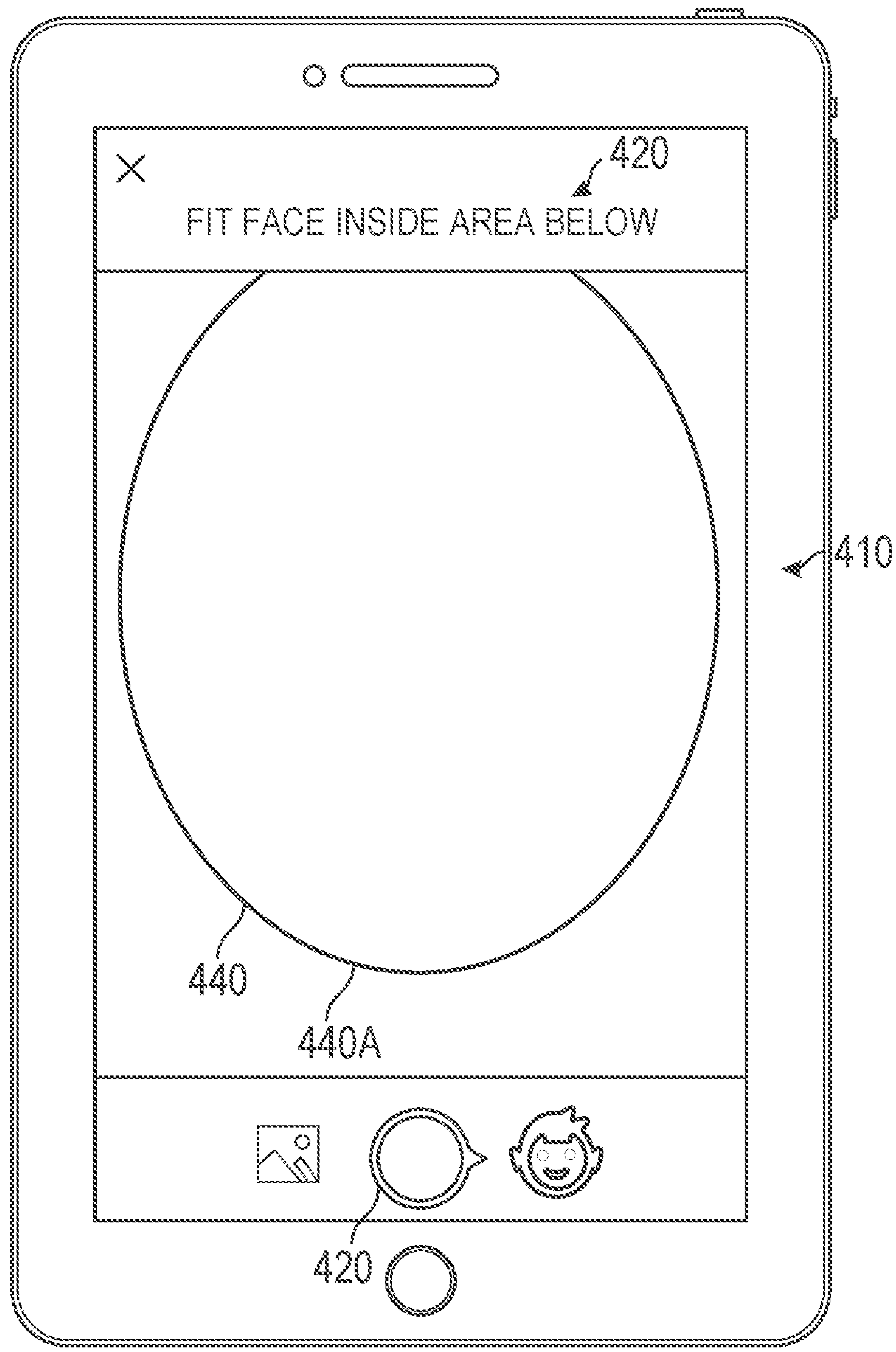


FIG. 4A

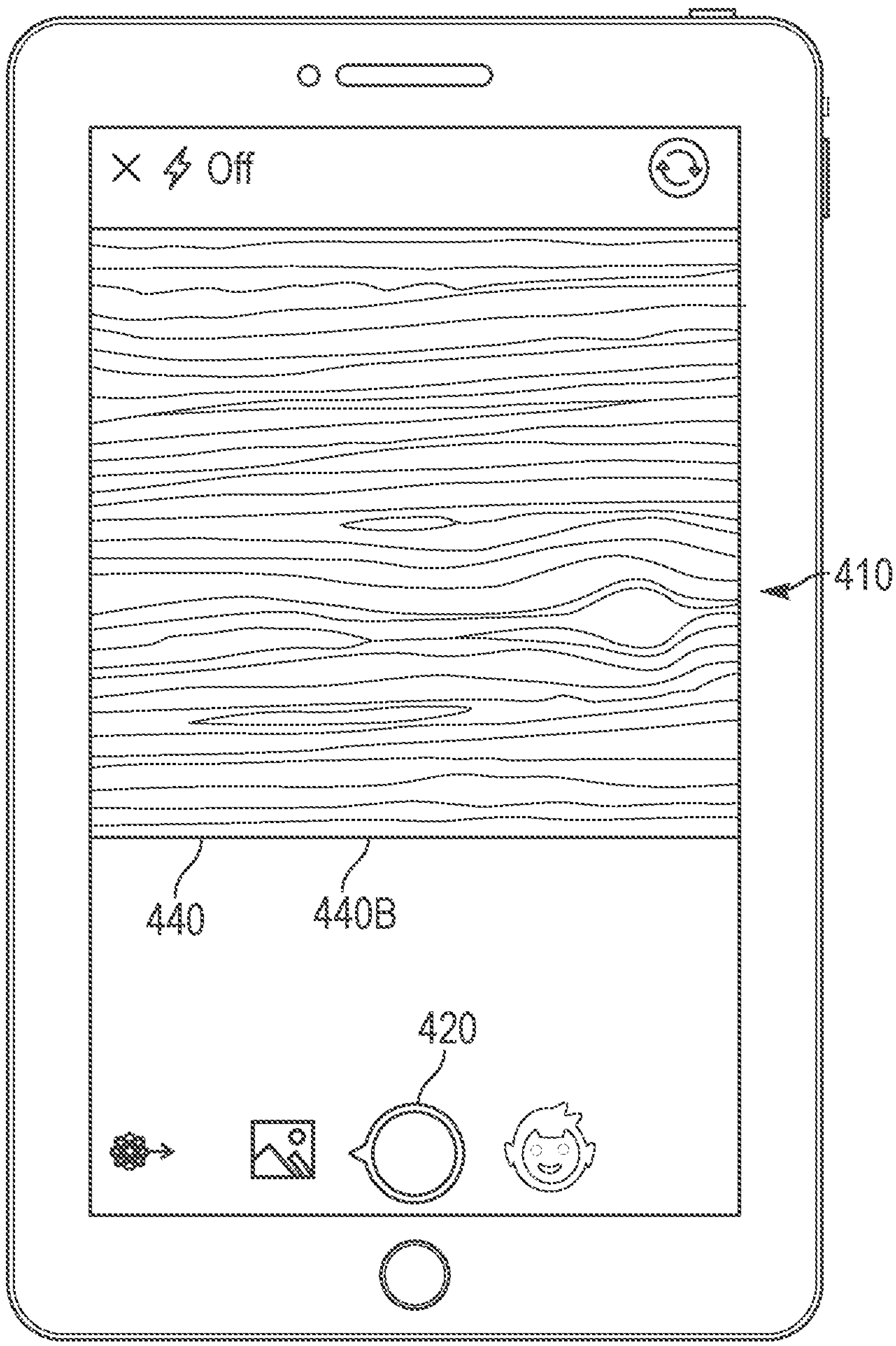


FIG. 4B

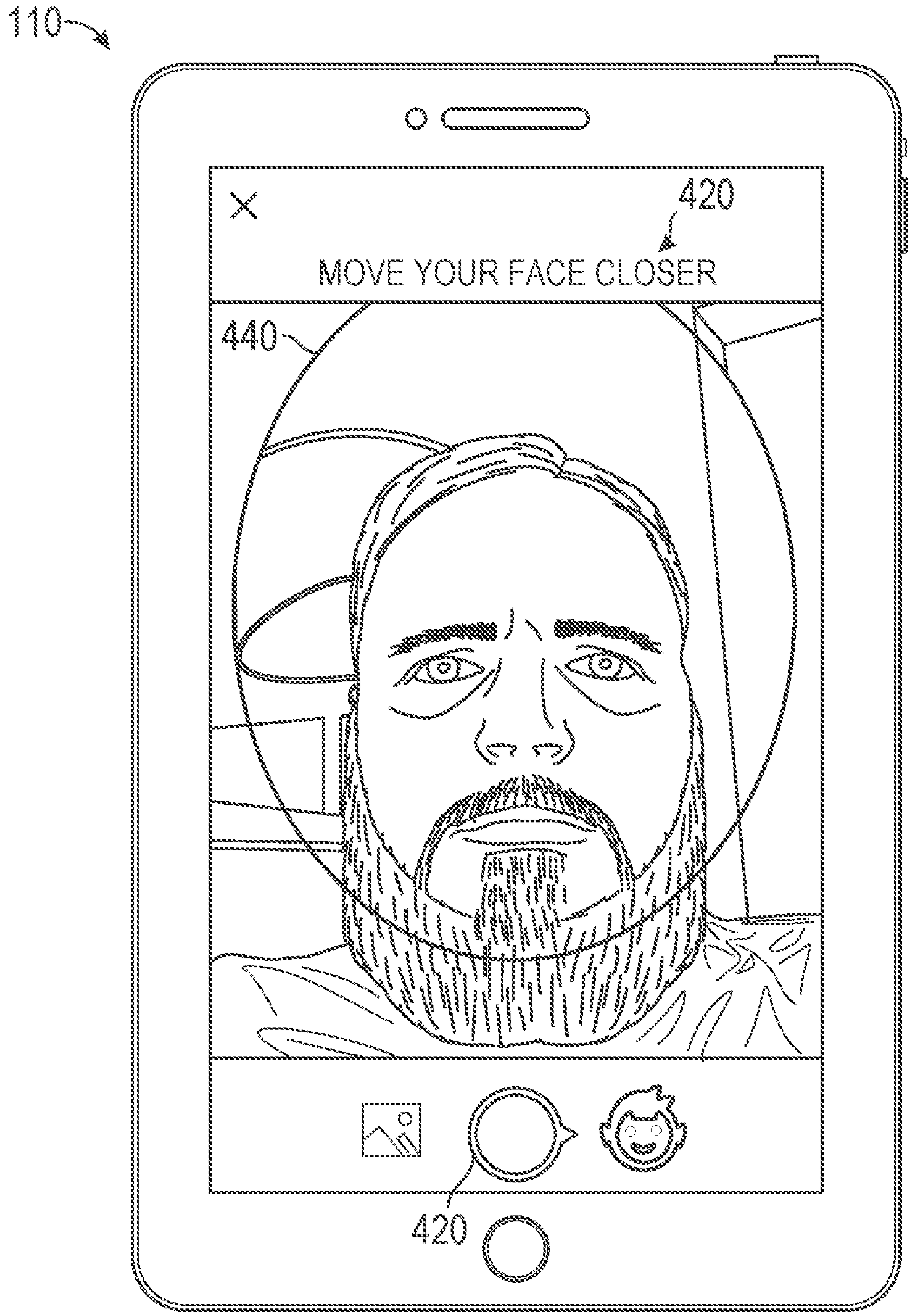


FIG. 5

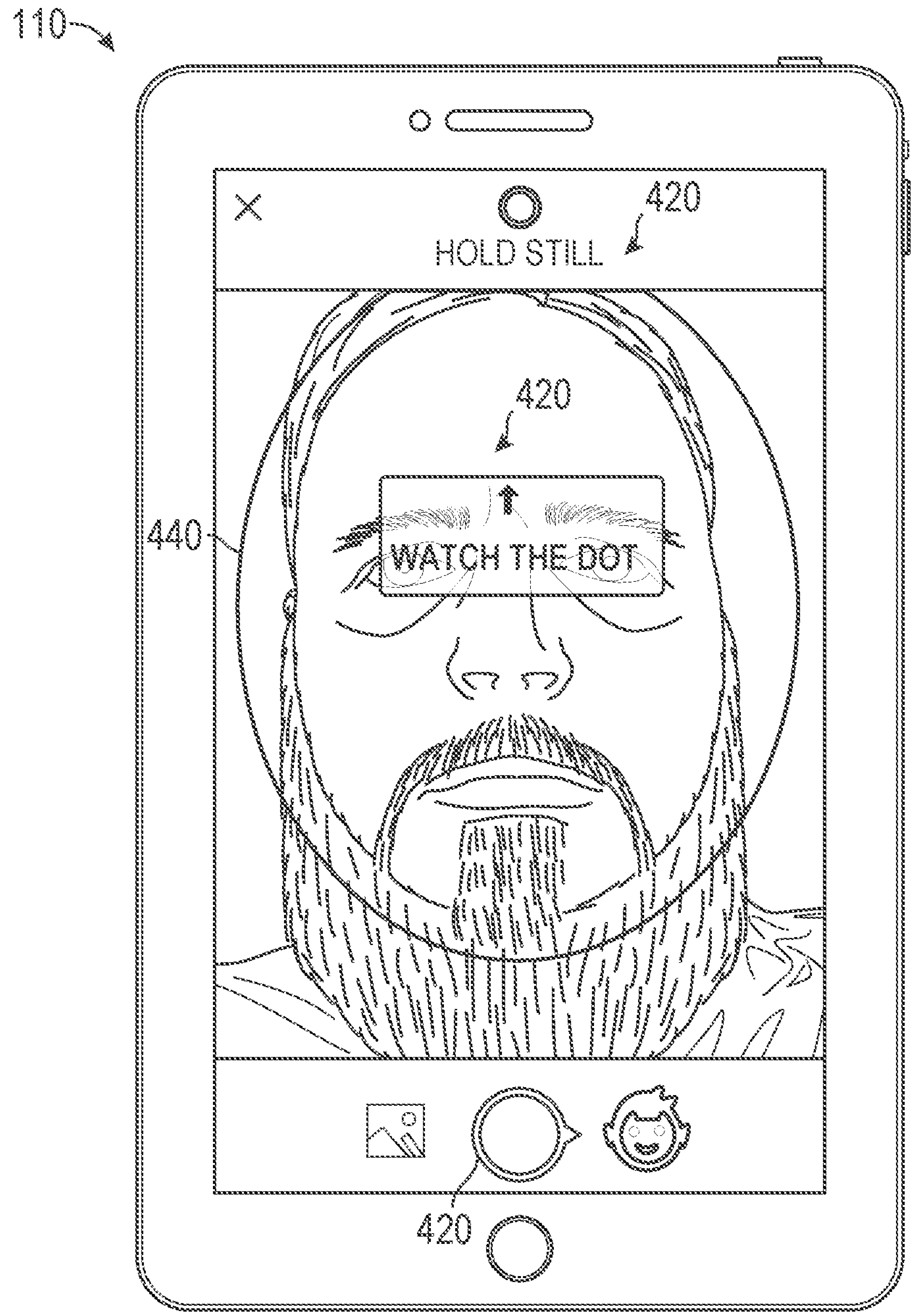


FIG. 6

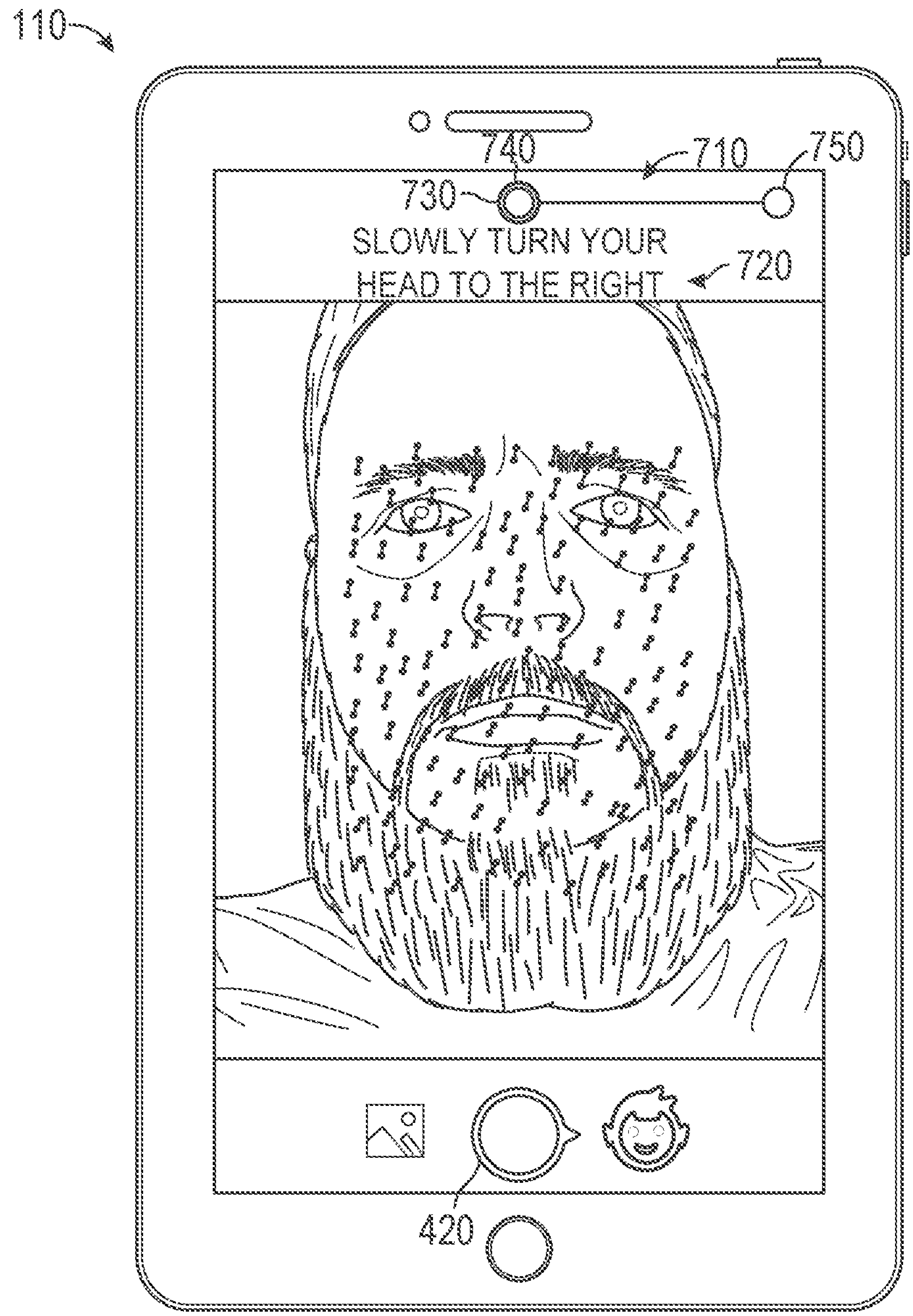


FIG. 7

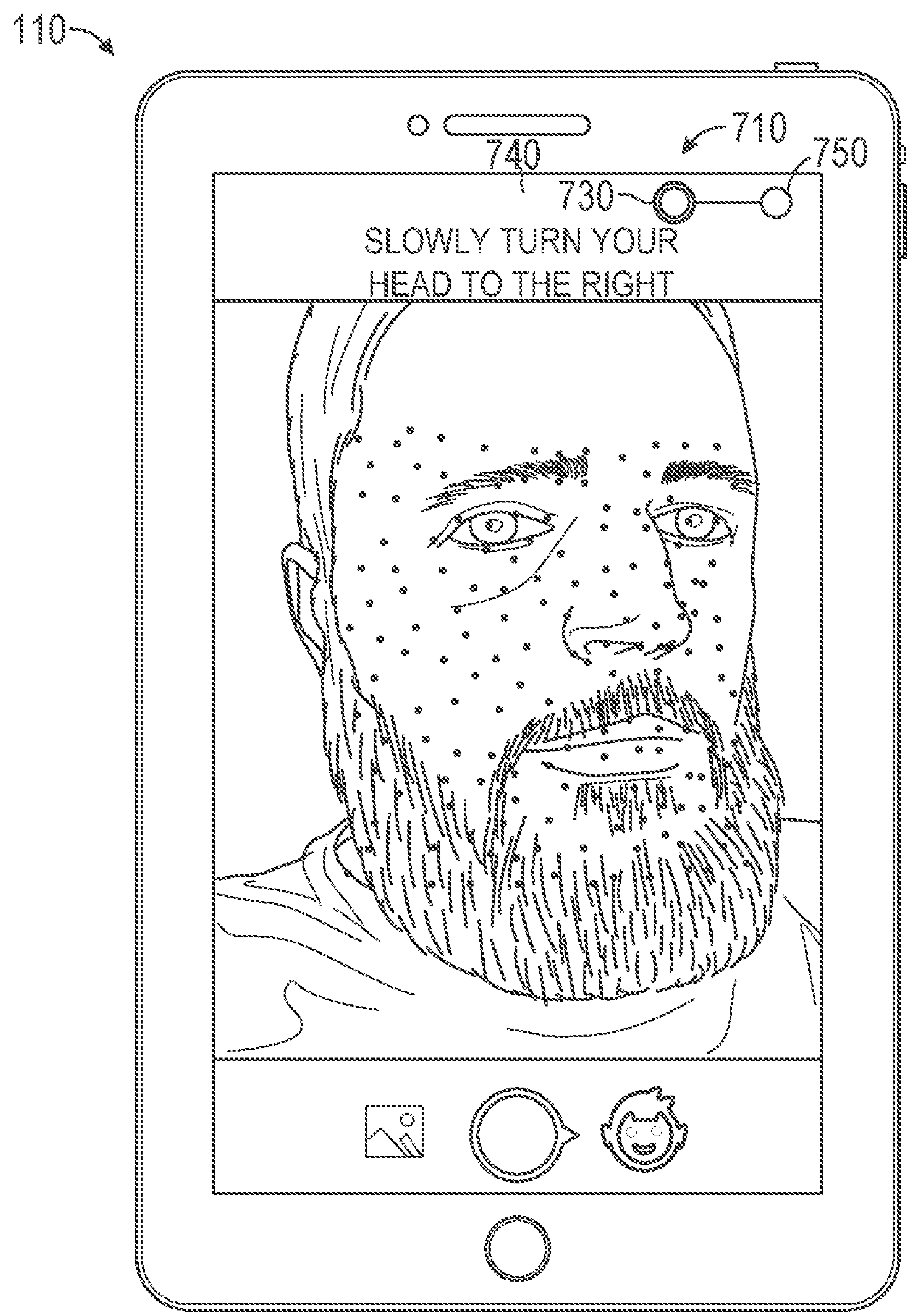


FIG. 8

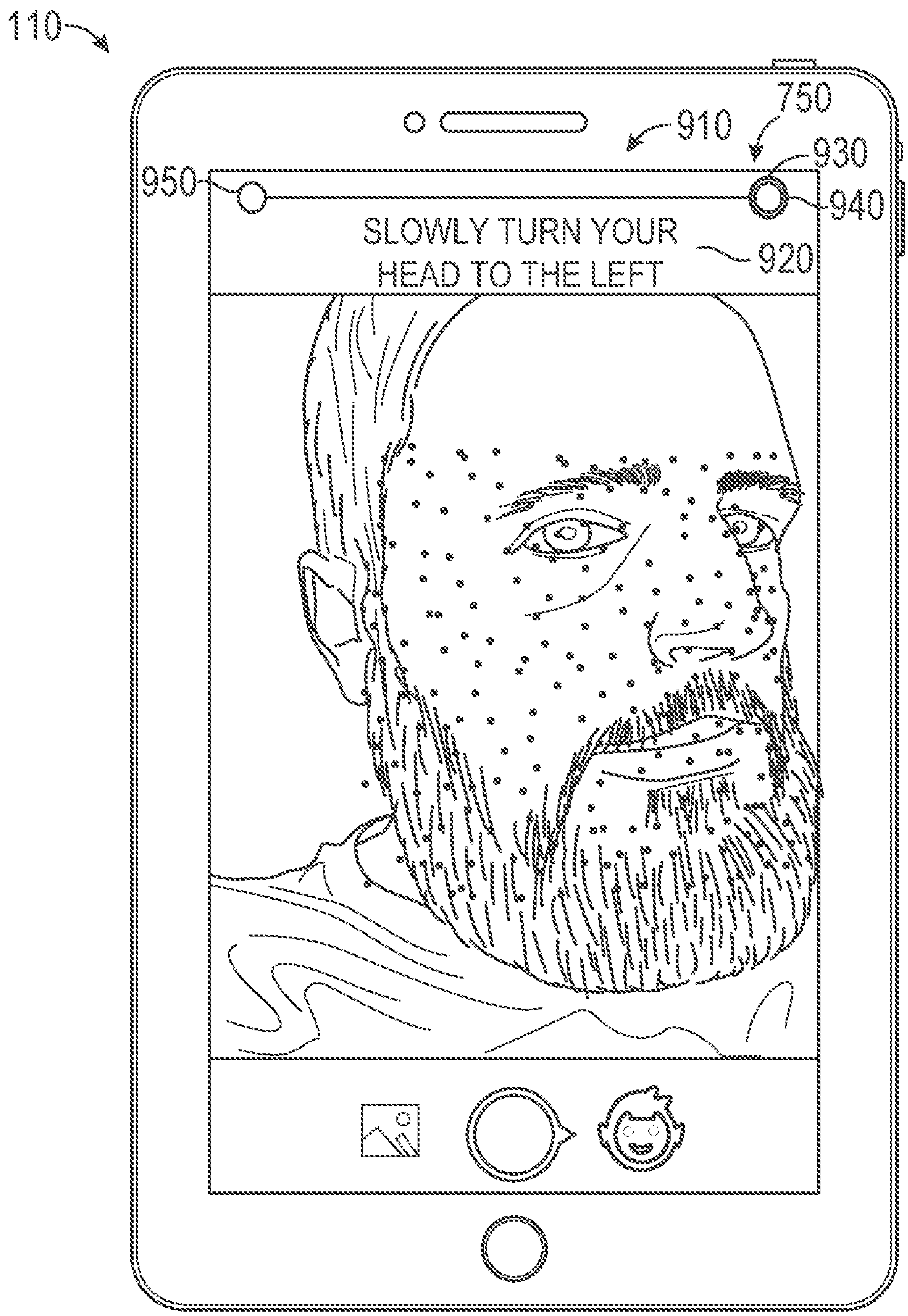


FIG. 9

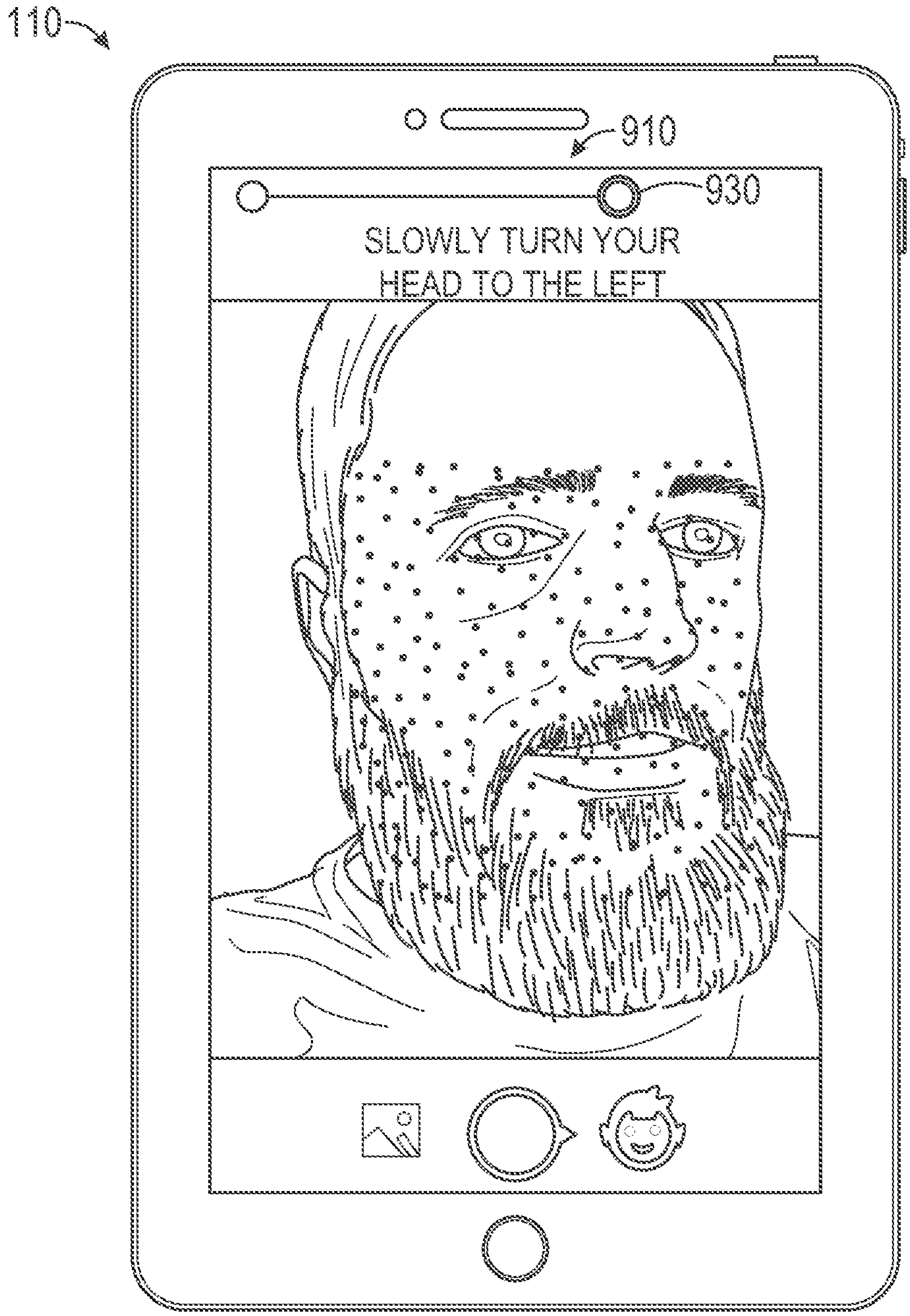


FIG. 10

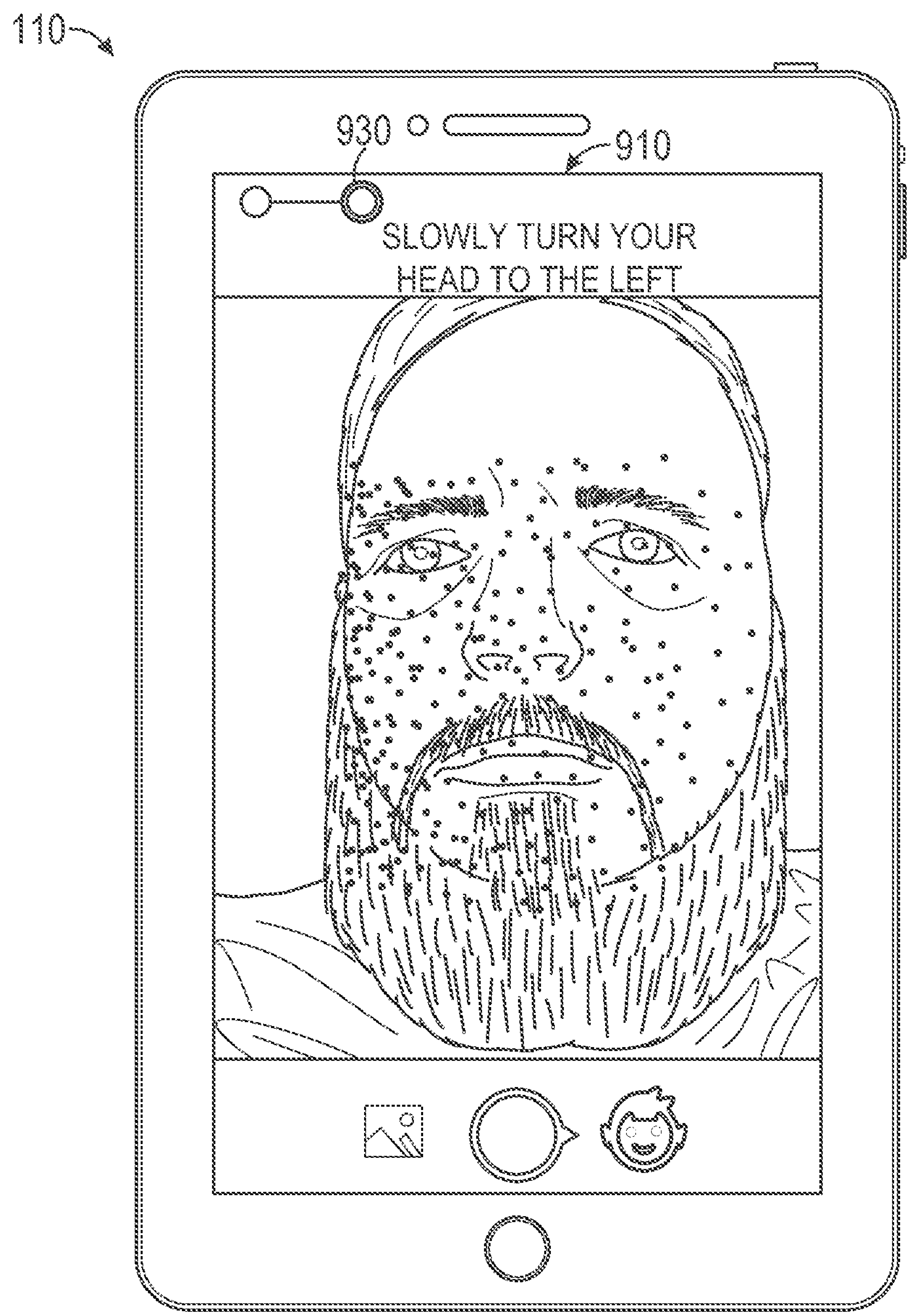


FIG. 11

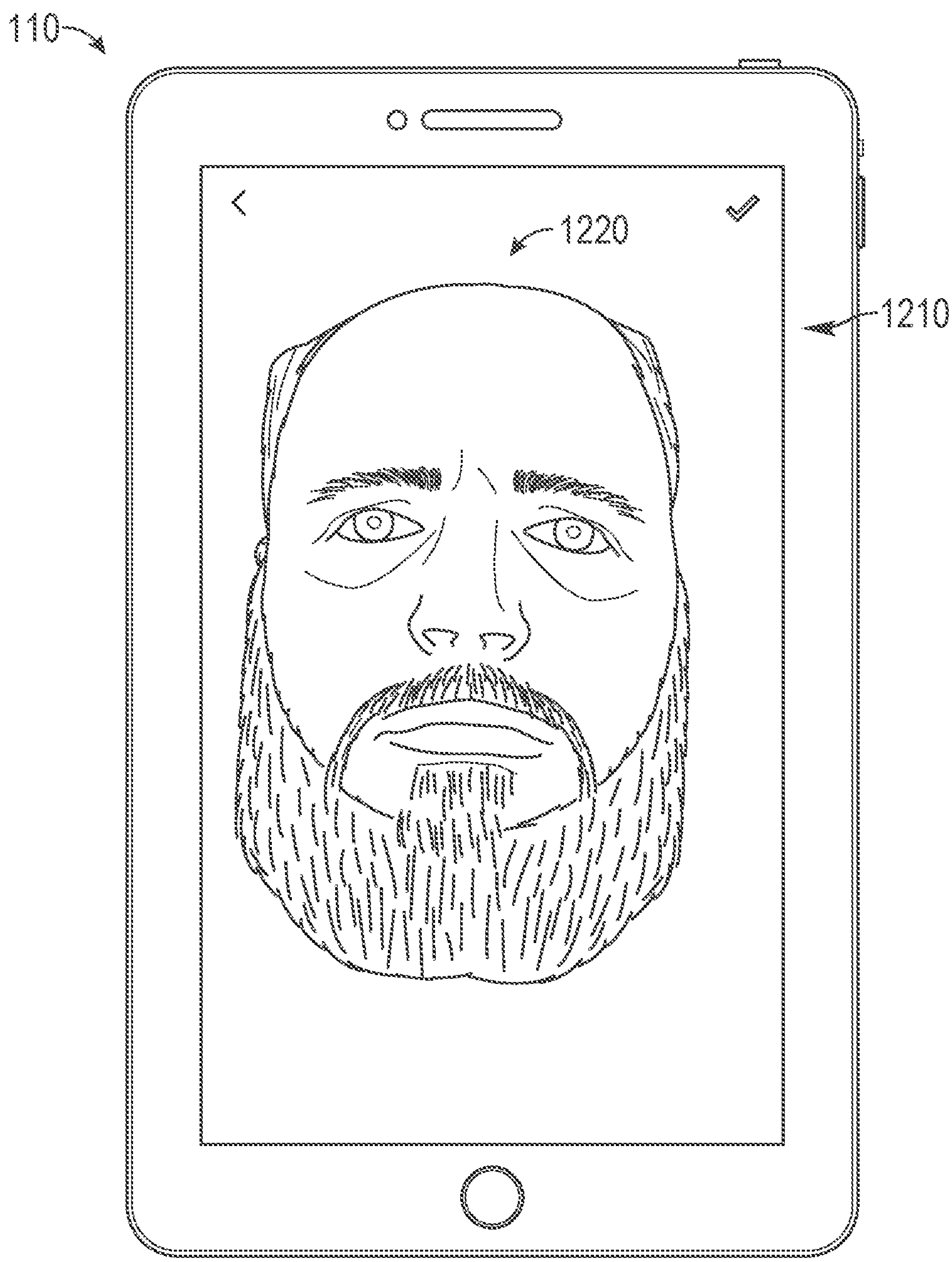


FIG. 12

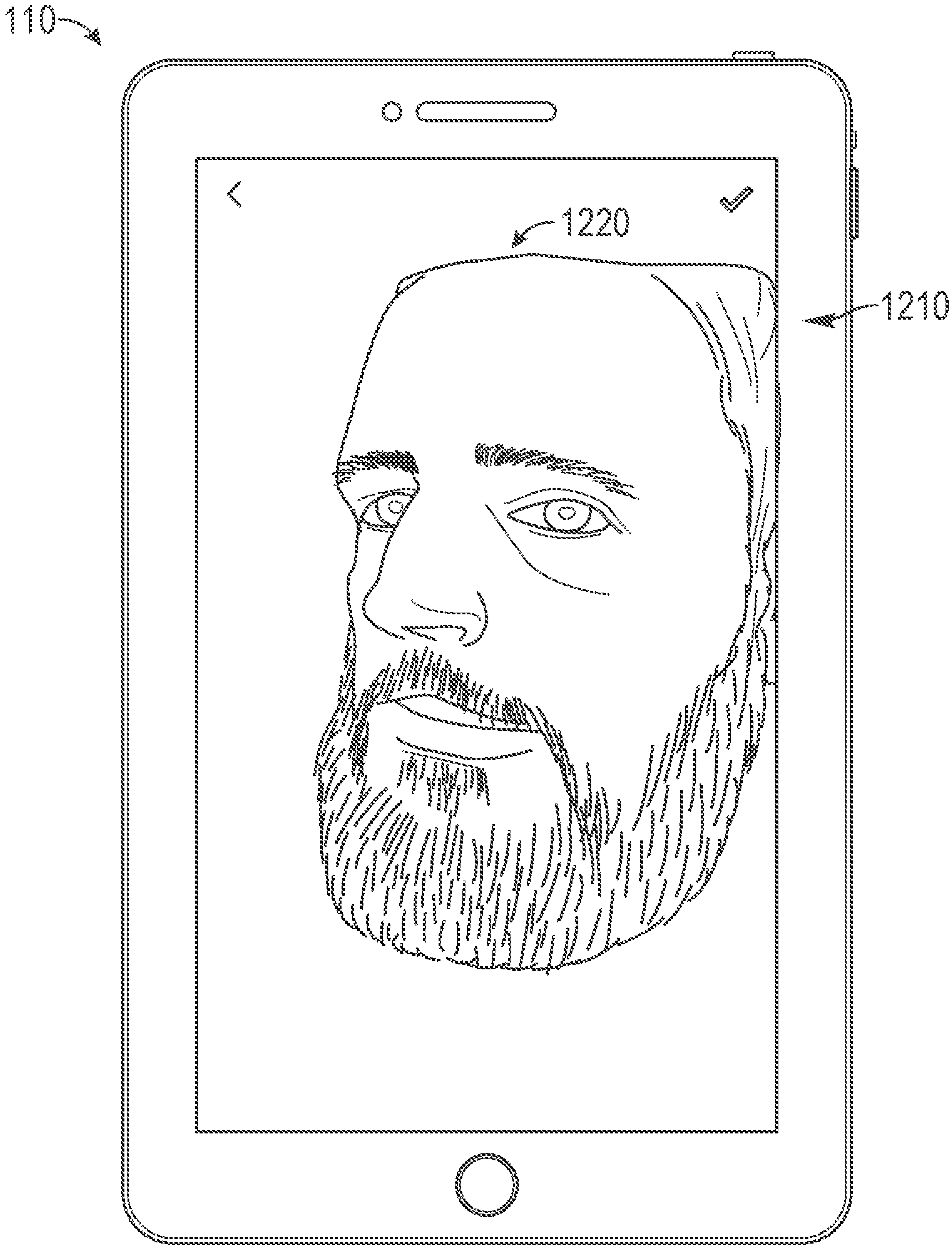


FIG. 13

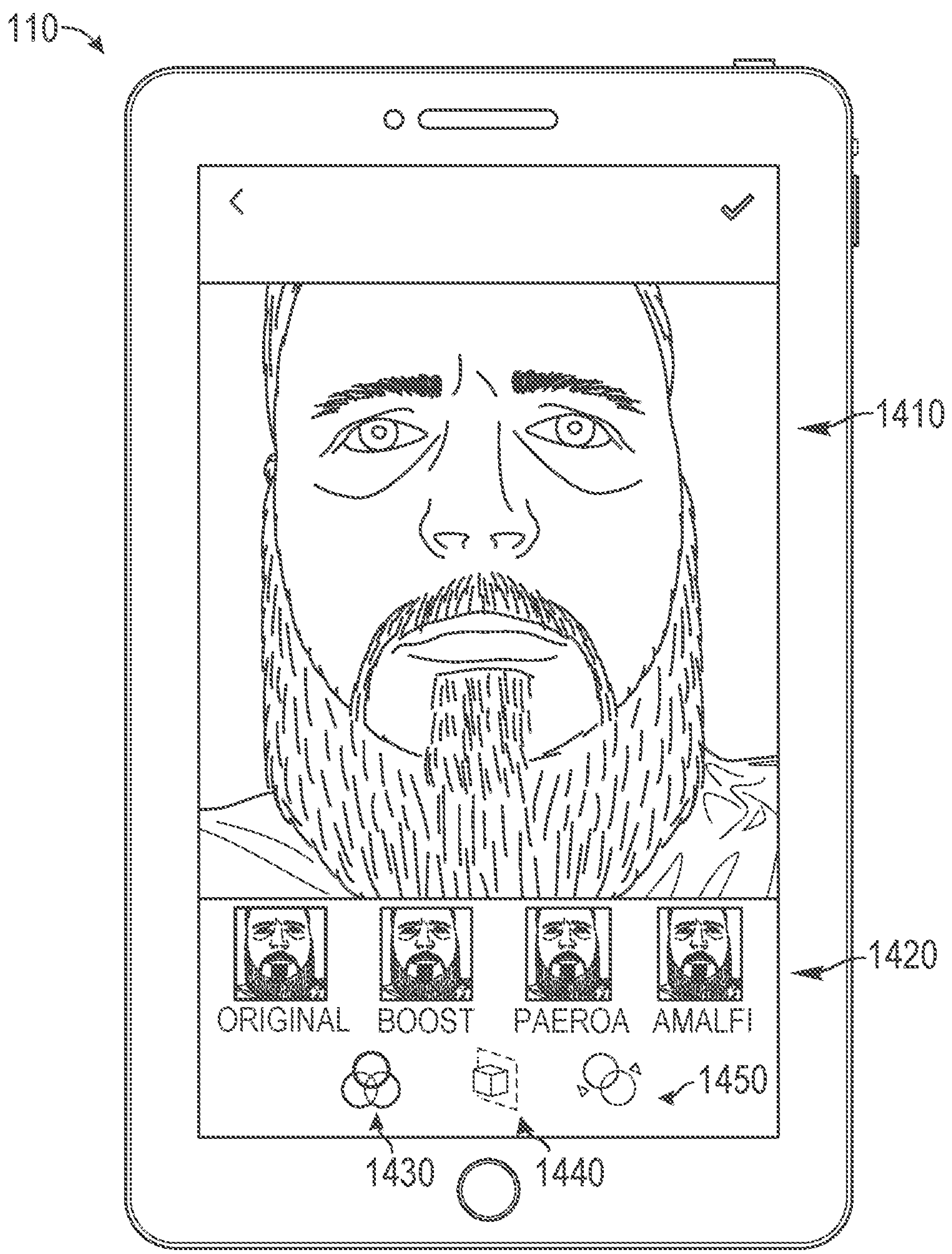


FIG. 14

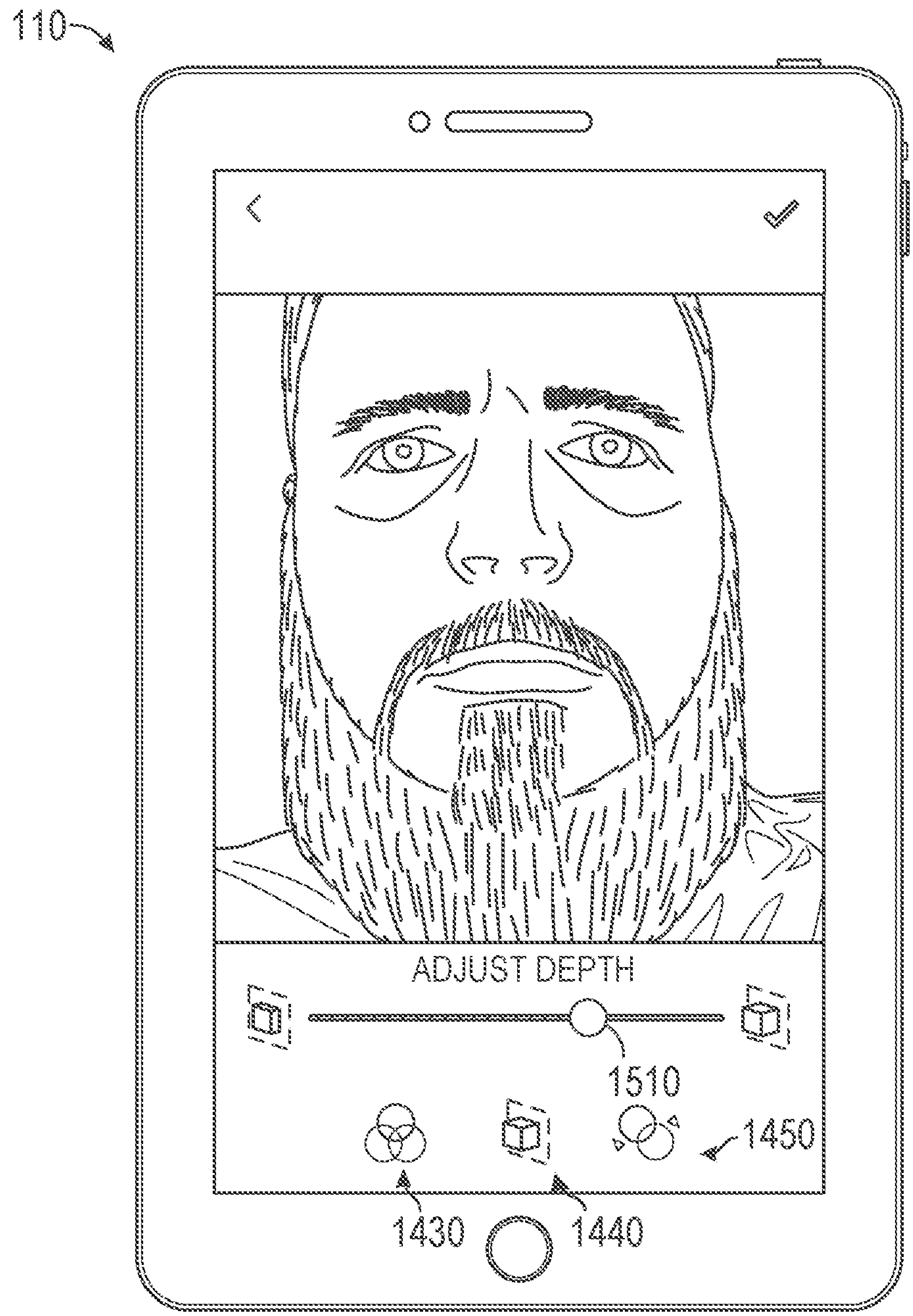


FIG. 15

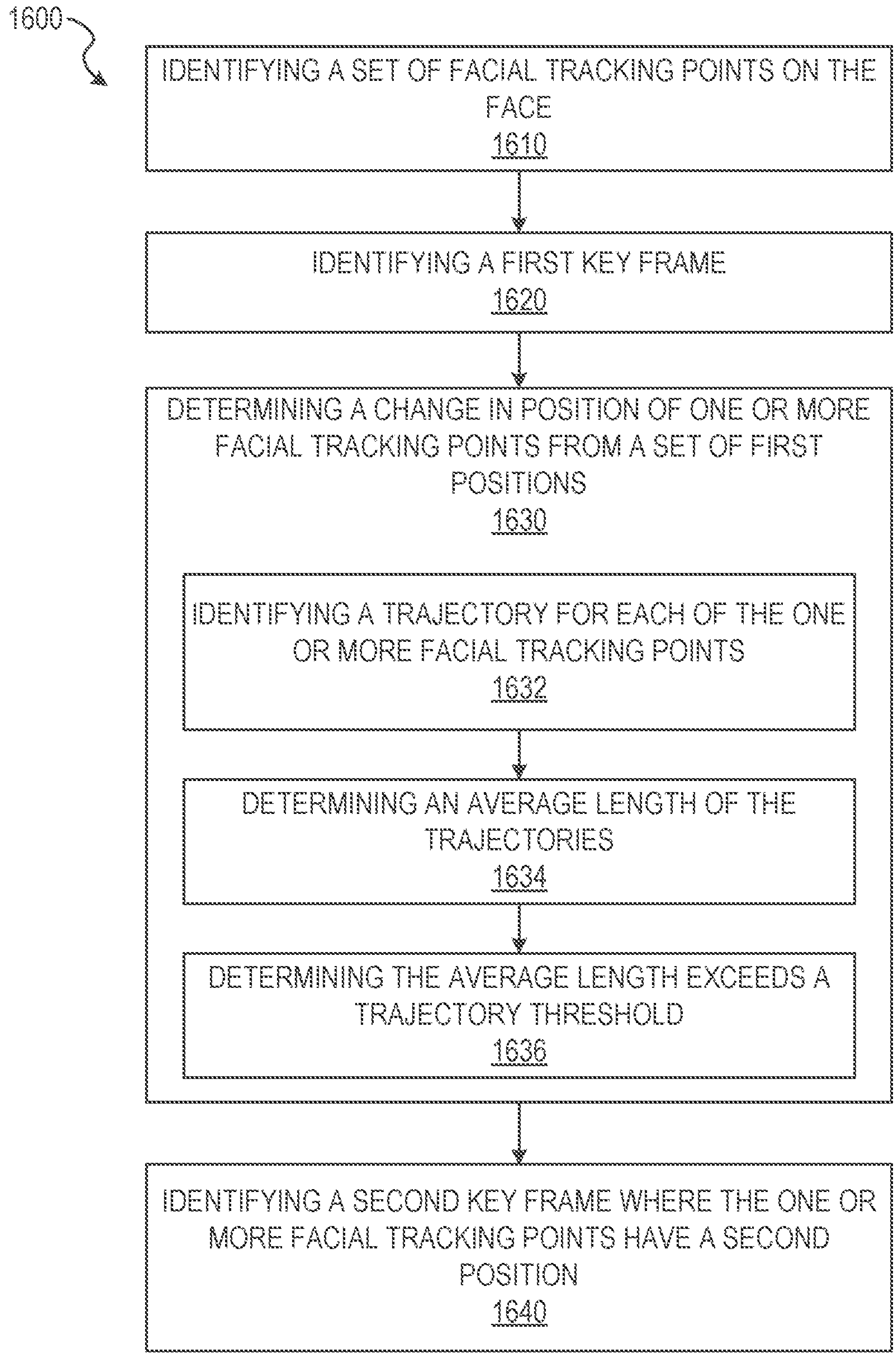

1600
IDENTIFYING A SET OF FACIAL TRACKING POINTS ON THE FACE
1610
IDENTIFYING A FIRST KEY FRAME
1620
DETERMINING A CHANGE IN POSITION OF ONE OR MORE FACIAL TRACKING POINTS FROM A SET OF FIRST POSITIONS
1630
IDENTIFYING A TRAJECTORY FOR EACH OF THE ONE OR MORE FACIAL TRACKING POINTS
1632
DETERMINING AN AVERAGE LENGTH OF THE TRAJECTORIES
1634
DETERMINING THE AVERAGE LENGTH EXCEEDS A TRAJECTORY THRESHOLD
1636
IDENTIFYING A SECOND KEY FRAME WHERE THE ONE OR MORE FACIAL TRACKING POINTS HAVE A SECOND POSITION
1640

FIG. 16

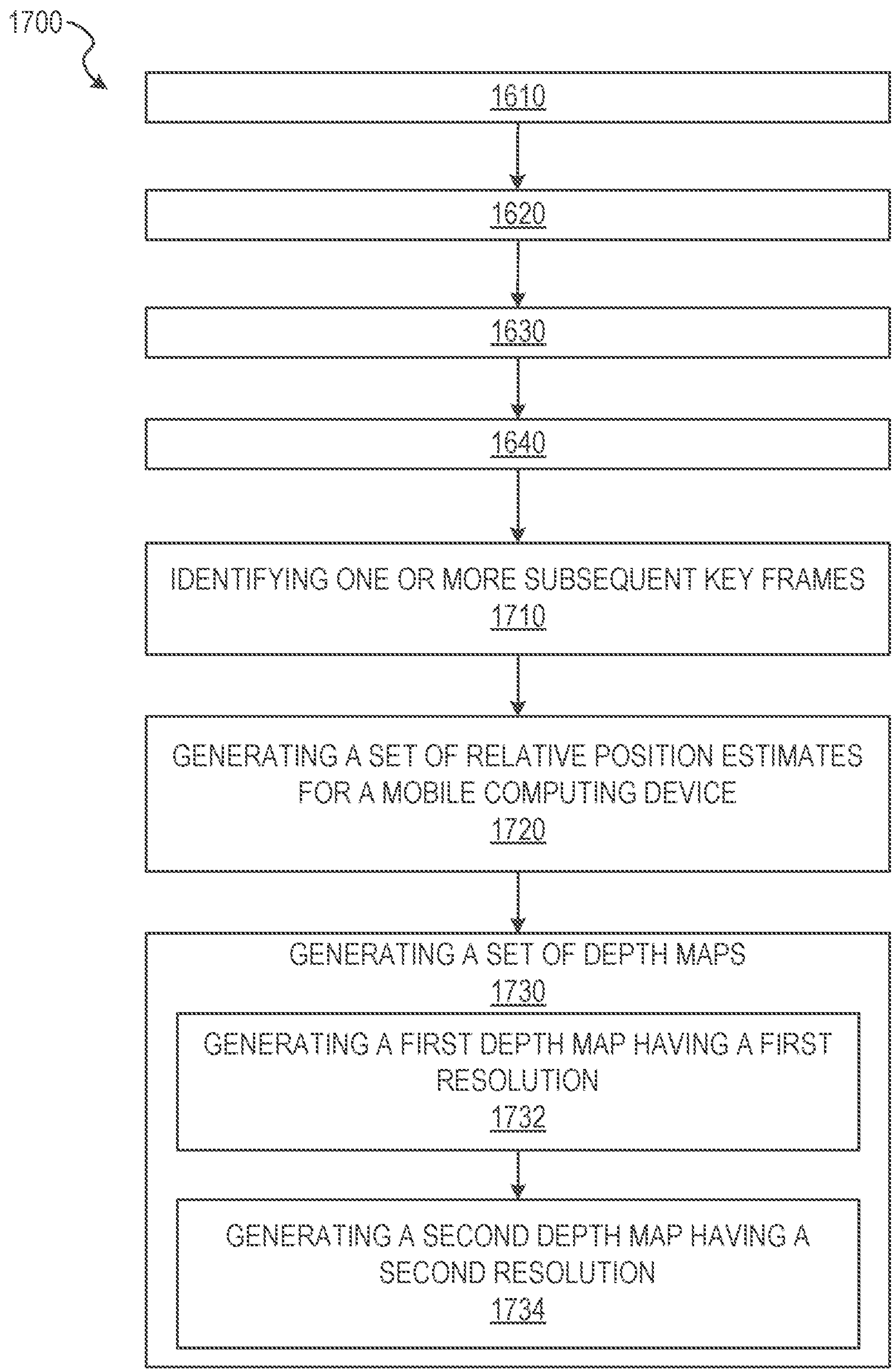

1700
1610
1620
1630
1640
IDENTIFYING ONE OR MORE SUBSEQUENT KEY FRAMES
1710
GENERATING A SET OF RELATIVE POSITION ESTIMATES FOR A MOBILE COMPUTING DEVICE
1720
GENERATING A SET OF DEPTH MAPS
1730
GENERATING A FIRST DEPTH MAP HAVING A FIRST RESOLUTION
1732
GENERATING A SECOND DEPTH MAP HAVING A SECOND RESOLUTION
1734

FIG. 17

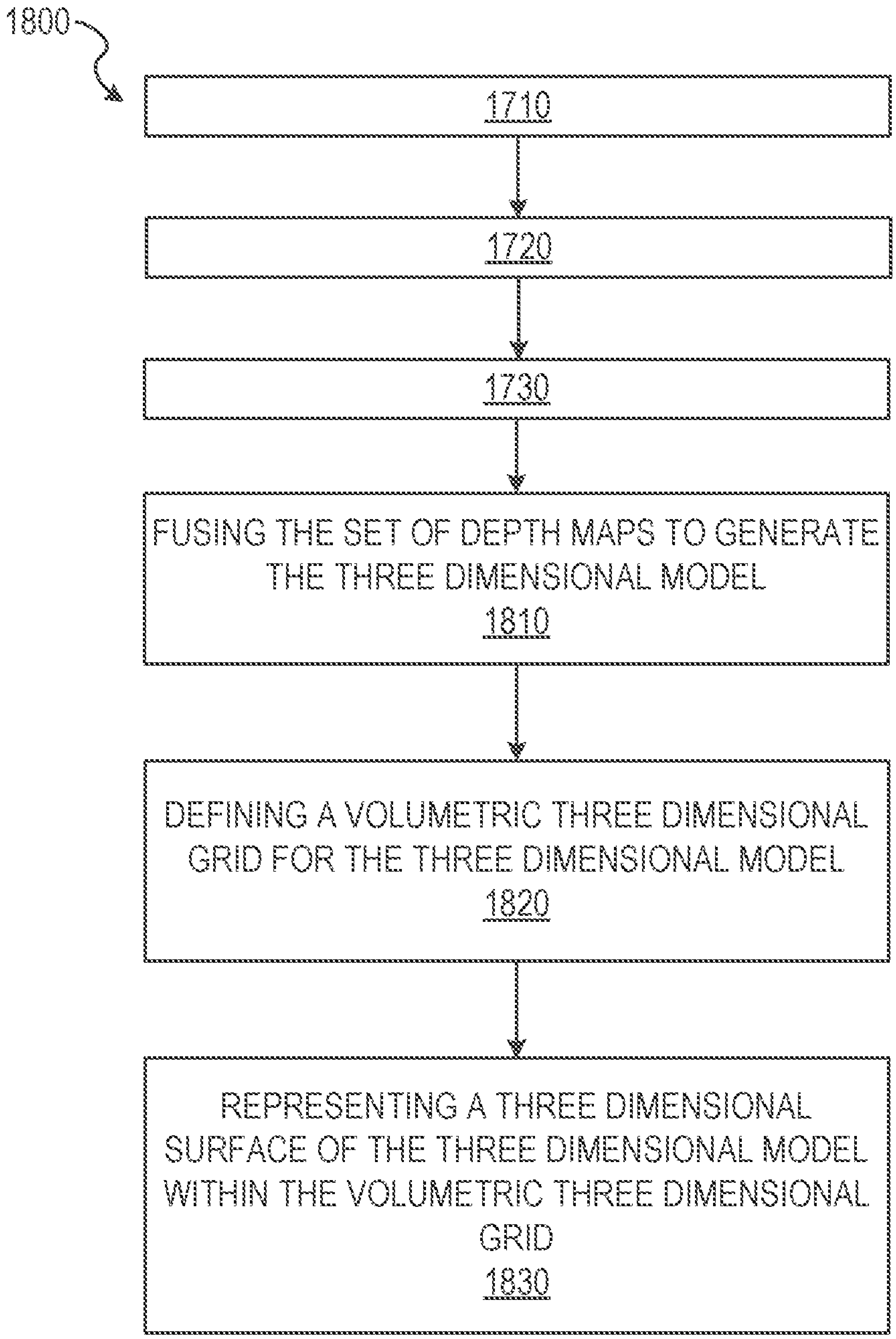

1800
1710
1720
1730
FUSING THE SET OF DEPTH MAPS TO GENERATE THE THREE DIMENSIONAL MODEL
1810
DEFINING A VOLUMETRIC THREE DIMENSIONAL GRID FOR THE THREE DIMENSIONAL MODEL
1820
REPRESENTING A THREE DIMENSIONAL SURFACE OF THE THREE DIMENSIONAL MODEL WITHIN THE VOLUMETRIC THREE DIMENSIONAL GRID
1830

FIG. 18

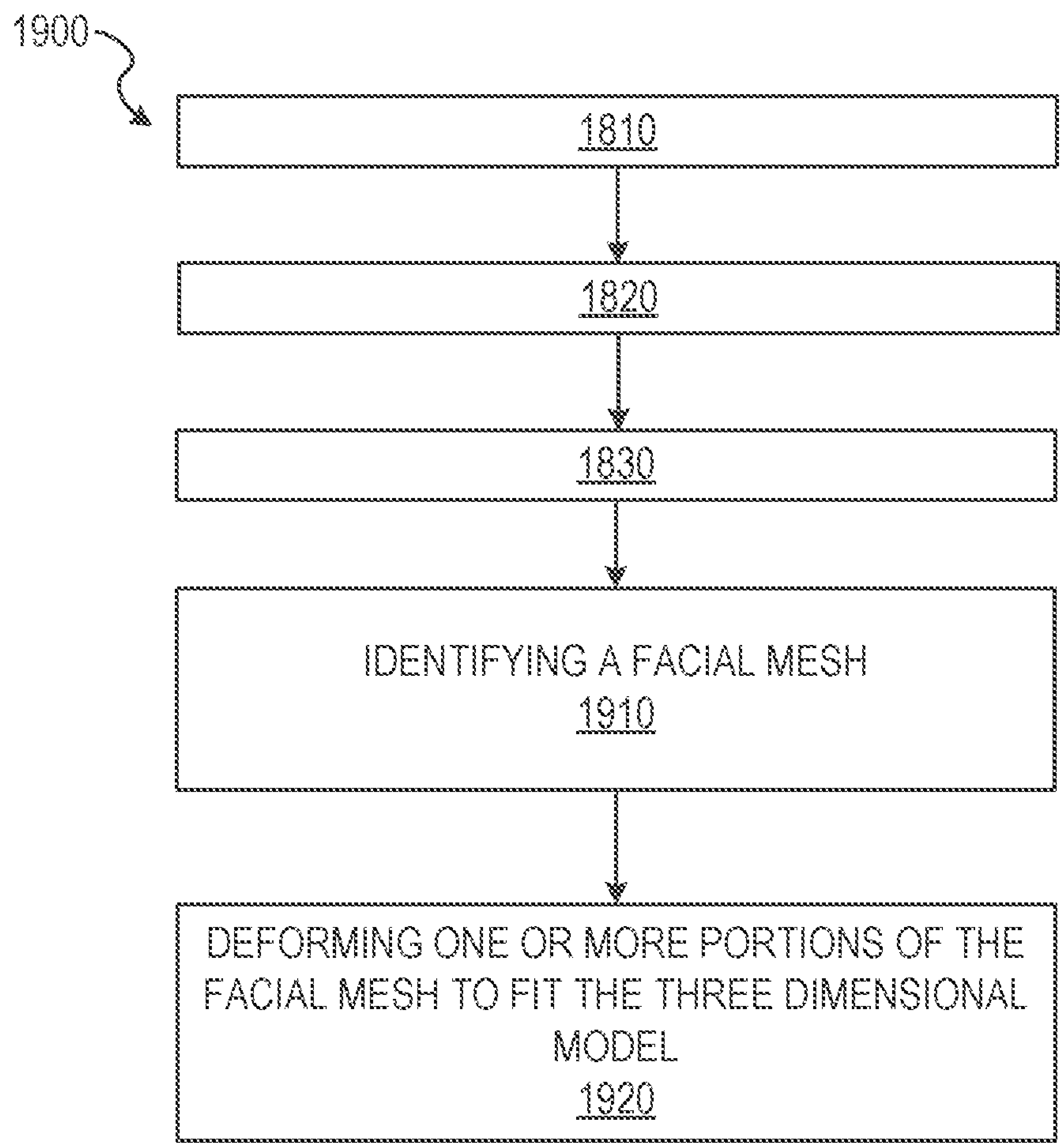

1900
1810
1820
1830
IDENTIFYING A FACIAL MESH
1910
DEFORMING ONE OR MORE PORTIONS OF THE FACIAL MESH TO FIT THE THREE DIMENSIONAL MODEL
1920

FIG. 19

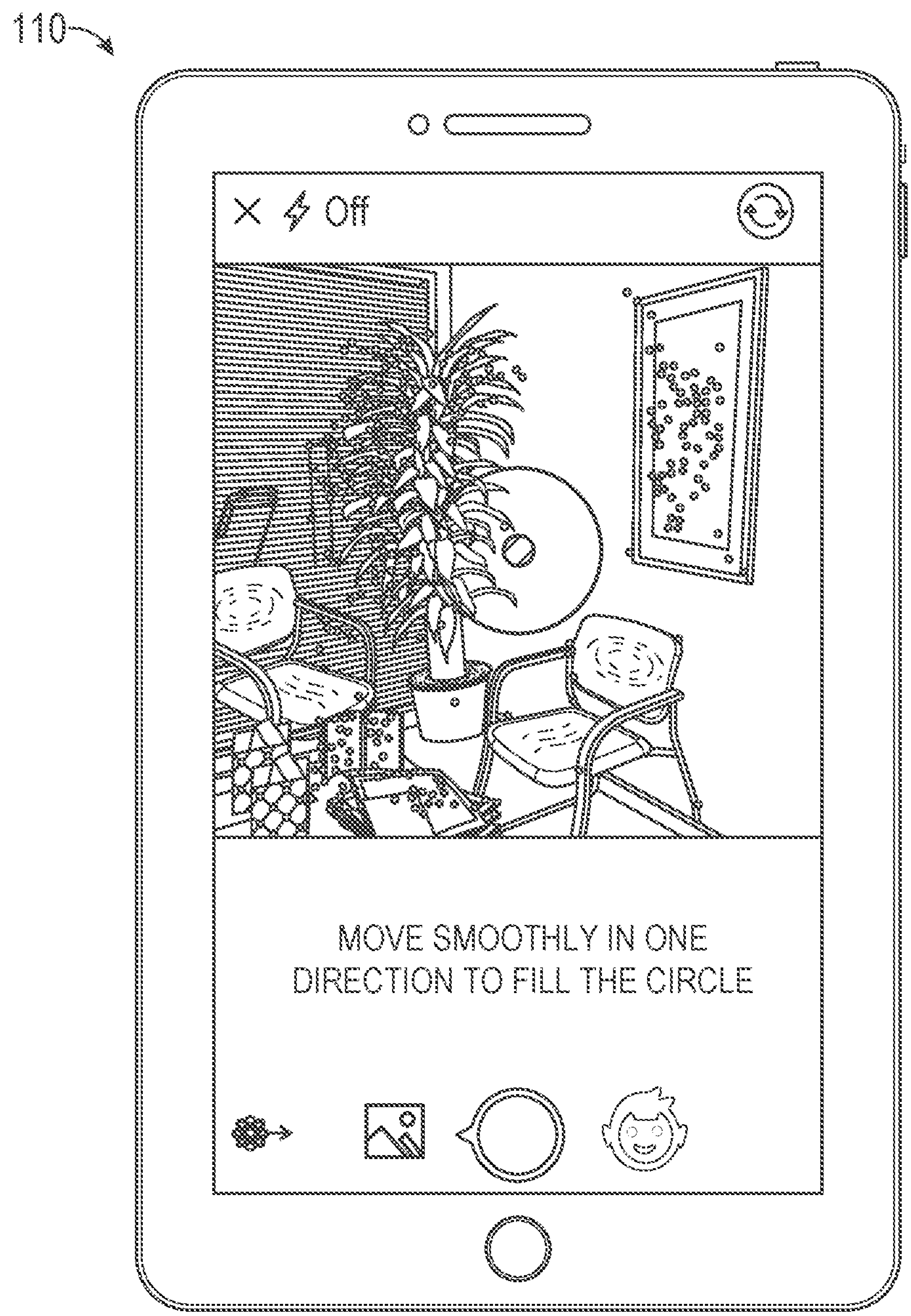


FIG. 20

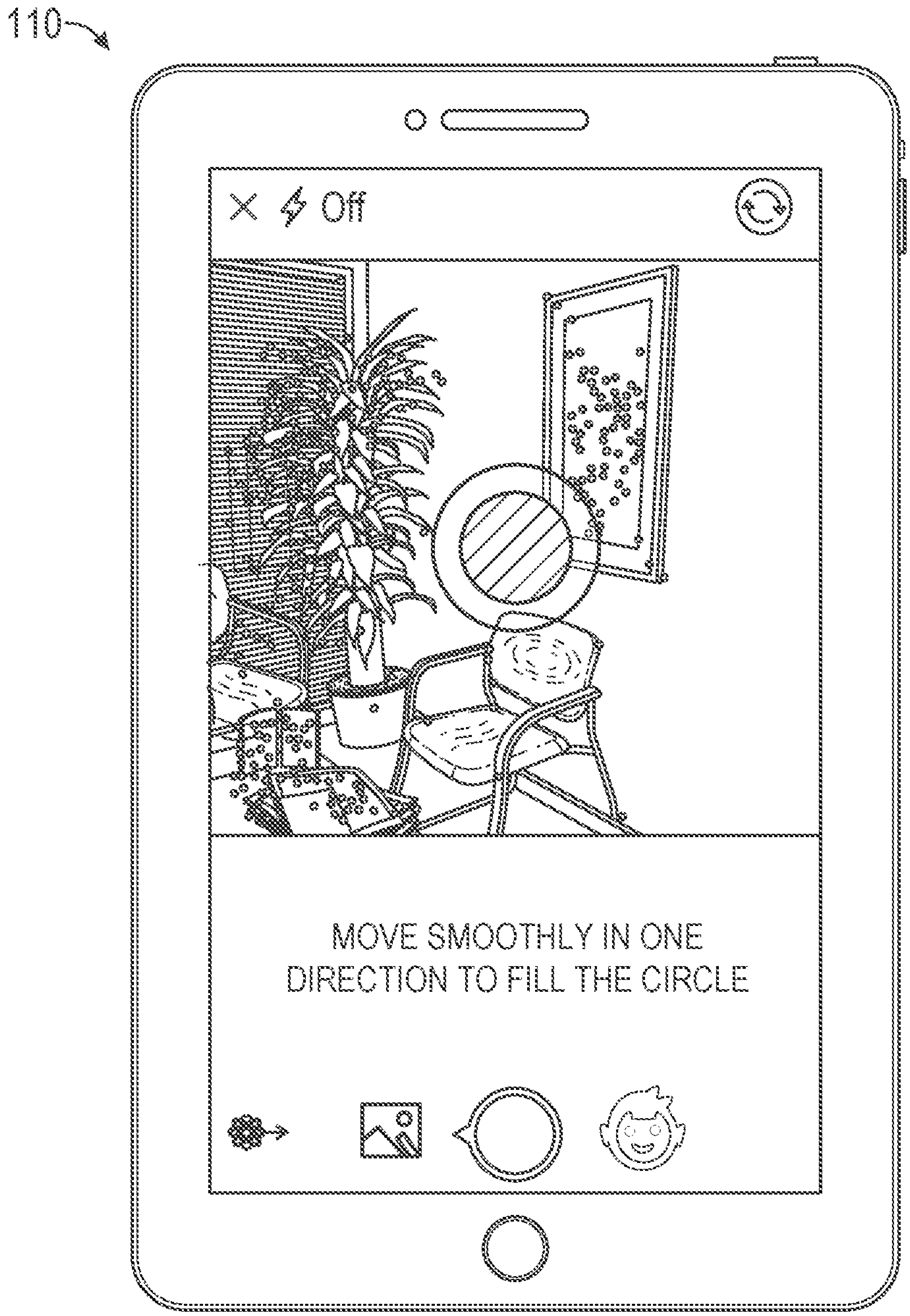


FIG. 21

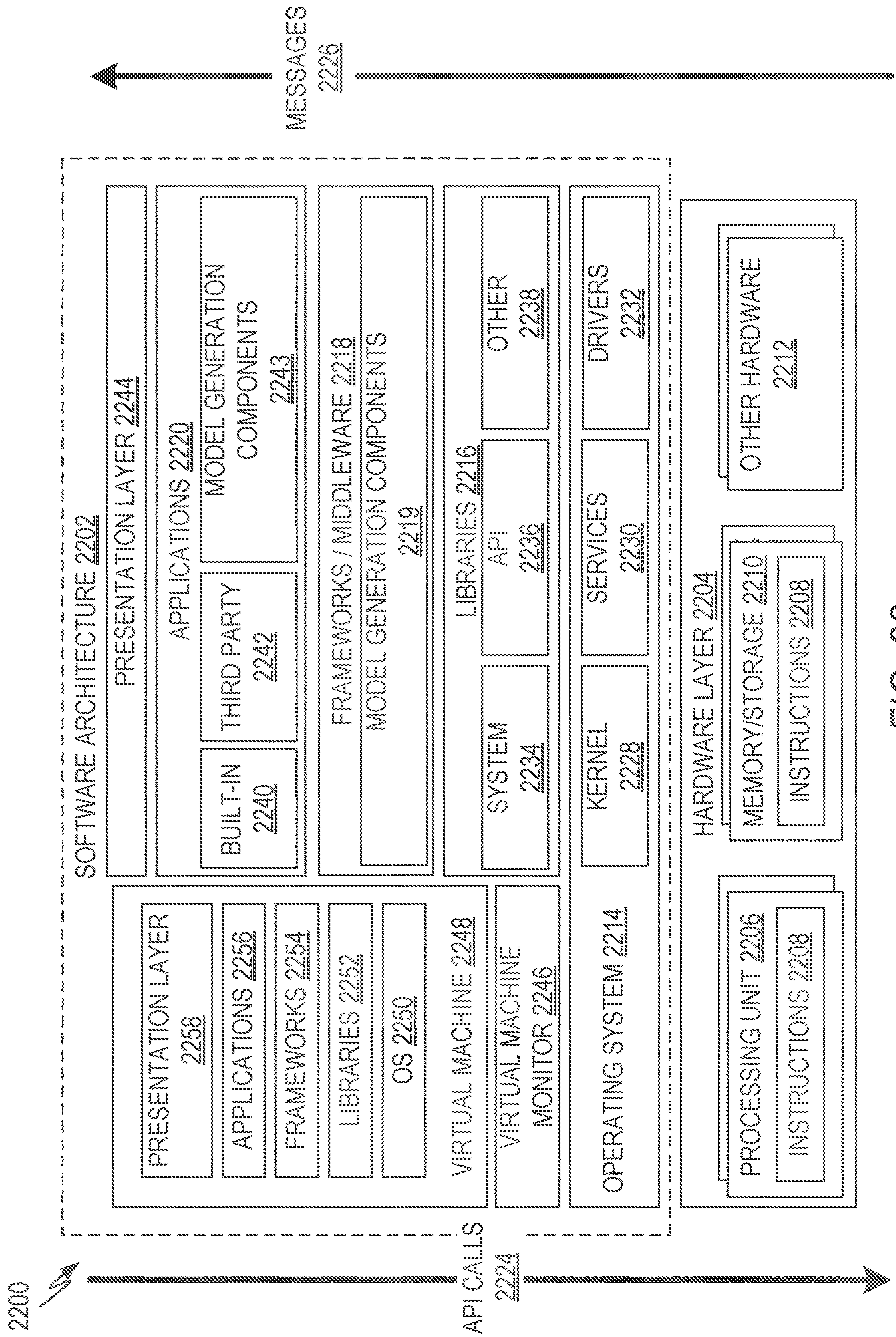

2200
MESSAGES 2226
API CALLS 2224
SOFTWARE ARCHITECTURE 2202
PRESENTATION LAYER 2244
APPLICATIONS 2220
BUILT-IN 2240
THIRD PARTY 2242
MODEL GENERATION COMPONENTS 2243
FRAMEWORKS / MIDDLEWARE 2218
MODEL GENERATION COMPONENTS 2219
LIBRARIES 2216
SYSTEM 2234
API 2236
OTHER 2238
KERNEL 2228
SERVICES 2230
DRIVERS 2232
OPERATING SYSTEM 2214
PRESENTATION LAYER 2258
APPLICATIONS 2256
FRAMEWORKS 2254
LIBRARIES 2252
OS 2250
VIRTUAL MACHINE 2248
VIRTUAL MACHINE MONITOR 2246
HARDWARE LAYER 2204
PROCESSING UNIT 2206
INSTRUCTIONS 2208
MEMORY/STORAGE 2210
INSTRUCTIONS 2208
OTHER HARDWARE 2212

FIG. 22

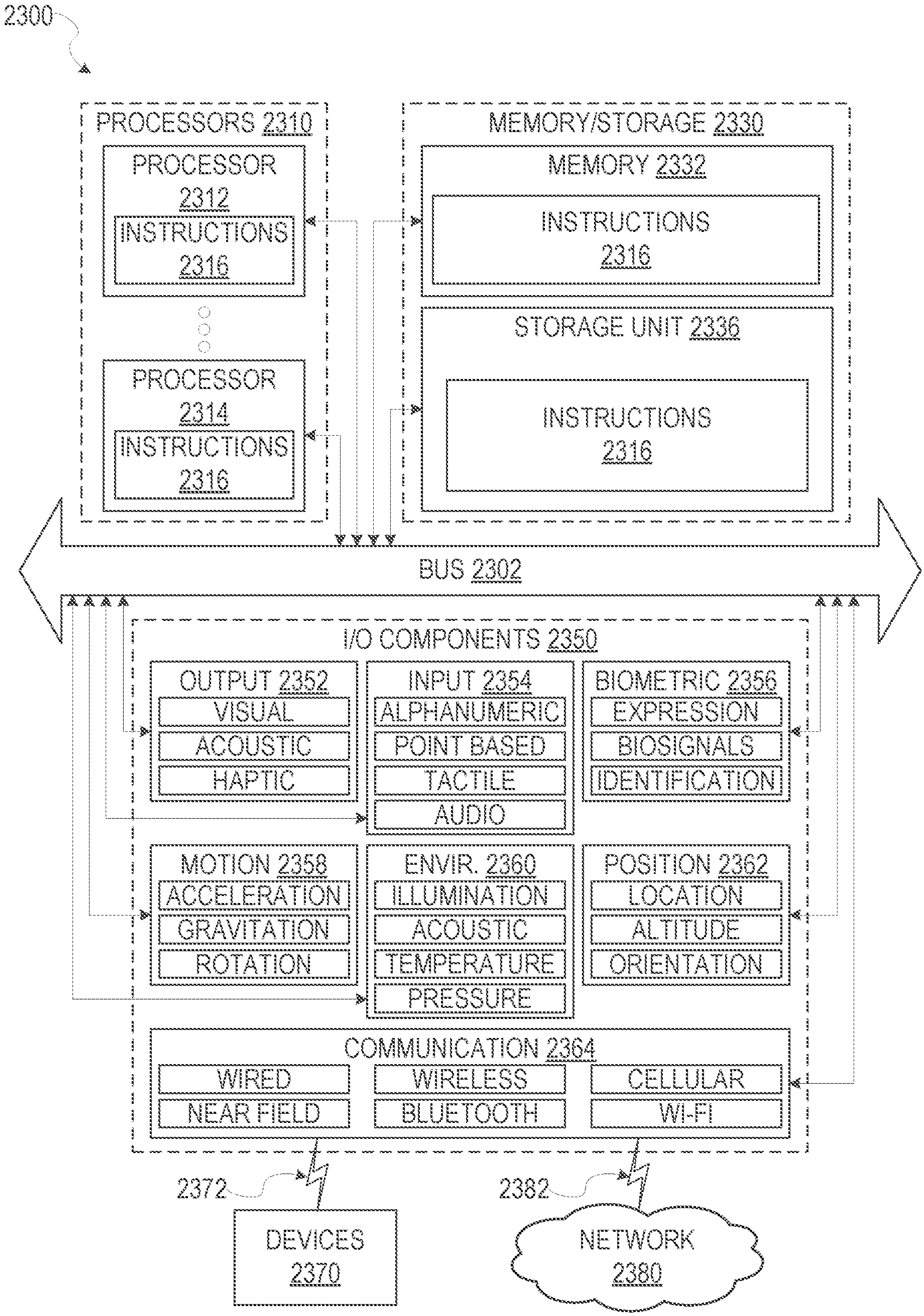

2300
PROCESSORS 2310
PROCESSOR 2312
INSTRUCTIONS 2316
PROCESSOR 2314
INSTRUCTIONS 2316
MEMORY/STORAGE 2330
MEMORY 2332
INSTRUCTIONS 2316
STORAGE UNIT 2336
INSTRUCTIONS 2316
BUS 2302
I/O COMPONENTS 2350
OUTPUT 2352
VISUAL
ACOUSTIC
HAPTIC
INPUT 2354
ALPHANUMERIC
POINT BASED
TACTILE
AUDIO
BIOMETRIC 2356
EXPRESSION
BIOSIGNALS
IDENTIFICATION
MOTION 2358
ACCELERATION
GRAVITATION
ROTATION
ENVIR. 2360
ILLUMINATION
ACOUSTIC
TEMPERATURE
PRESSURE
POSITION 2362
LOCATION
ALTITUDE
ORIENTATION
COMMUNICATION 2364
WIRED
WIRELESS
CELLULAR
NEAR FIELD
BLUETOOTH
WI-FI
2372
2382
DEVICES 2370
NETWORK 2380

FIG. 23

AUTOMATED THREE DIMENSIONAL MODEL GENERATION

CLAIM OF PRIORITY

This application is a continuation of and claims the benefit of U.S. patent application Ser. No. 16/226,108, filed on Dec. 19, 2018, which is a continuation of and claims the benefit of priority of U.S. patent application Ser. No. 15/816,795, filed Nov. 17, 2017, which is a continuation of and claims the benefit of U.S. patent application Ser. No. 15/080,357, filed Mar. 24, 2016, which claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. No. 62/139,009, filed on Mar. 27, 2015, the benefit of priority of each of which are claimed hereby, and each of which are incorporated by reference herein in their entirety.

TECHNICAL FIELD

Embodiments of the present disclosure relate generally to three dimensional model generation and, more particularly, but not by way of limitation, to generating three dimensional models based on directed movement of an object to be modeled with respect to an image capture device.

BACKGROUND

Conventionally, systems and methods for generating three dimensional models are third party systems located remotely from an intended recipient of the model. Generation of three dimensional models often employs sets of static images captured in advance of model generation. Systems and methods of generating three dimensional images often perform computationally intensive operations to generate and animate the three dimensional models.

BRIEF DESCRIPTION OF THE DRAWINGS

Various ones of the appended drawings merely illustrate example embodiments of the present disclosure and cannot be considered as limiting its scope.

FIG. **1** is a block diagram illustrating a networked system, according to some example embodiments.

FIG. **2** is a block diagram of an example model generation system, according to various embodiments.

FIG. **3** is a flowchart illustrating an example method of generating three dimensional models within a graphical user interface, according to various embodiments.

FIG. **4**A is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **4**B is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **5** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **6** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **7** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **8** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **9** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **10** is an example interface diagram illustrating a user interface screen of a model generation system according to various embodiments.

FIG. **11** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **12** is an example interface diagram illustrating a three dimensional model according to various embodiments.

FIG. **13** is an example interface diagram illustrating a three dimensional model, according to various embodiments.

FIG. **14** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **15** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **16** is a flowchart illustrating an example method for generating three dimensional models within a graphical user interface, according to various embodiments.

FIG. **17** is a flowchart illustrating an example method of generating three dimensional models within a graphical user interface, according to various embodiments.

FIG. **18** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **19** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **20** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **21** is an example interface diagram illustrating a user interface screen of a model generation system, according to various embodiments.

FIG. **22** is a block diagram illustrating an example of a software architecture that may be installed on a machine, according to some example embodiments.

FIG. **23** illustrates a diagrammatic representation of a machine in the form of a computer system within which a set of instructions may be executed for causing the machine to perform any one or more of the methodologies discussed herein, according to an example embodiment.

The headings provided herein are merely for convenience and do not necessarily affect the scope or meaning of the terms used.

DETAILED DESCRIPTION

The description that follows includes systems, methods, techniques, instruction sequences, and computing machine program products that embody illustrative embodiments of the disclosure. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide an understanding of various embodiments of the inventive subject matter. It will be evident, however, to those skilled in the art, that embodiments of the inventive subject matter may be practiced without these specific details. In general, well-known instruction instances, protocols, structures, and techniques are not necessarily shown in detail.

The systems and methods described herein enable an untrained individual to use a computing device (e.g., a smartphone or tablet), with one or more image capture devices (e.g., cameras) attached, to create, without the aid of other people, a fitted canonical three dimensional (3D) mesh model of an object. In some embodiments, the object may be the individual's face, hand, arm, leg, or other body part; an object of an identified type (e.g., a car, a cup, a couch, a desk, or other defined object). The systems and methods allows 3D face models to be imported, visualized, and/or manipulated in other software programs and computing systems that contain or display 3D graphics, such as video games, virtual reality environments, and commerce platforms. The 3D face models may be used for personalization of products, services, experiences, game play, graphical content, identification, and data analysis.

In some embodiments, the systems and methods described herein may form all or part of an end-user application (EUA). The EUA may be a software program including user interface elements that enable untrained end users to initiate the EUA on a computing device that has one or more cameras attached, such as (but not limited to) a computer, laptop, IPAD, smartphone, tablet computer, or any other mobile computing device available to the user. In some embodiments, the EUA may be a stand-alone program. The EUA may also be a part of or embedded within another software program.

The EUA permits the untrained user, without the assistance of other people, to create a fitted canonical 3D mesh model of their own face. The EUA may include one or more components described below for generating depth maps, fusing depth maps to generate 3D models, object mesh fitting, model review, and data transmission. The EUA components that provide the 3D data capture, model creation, and completed model data transmission are described in detail below. These components manipulate the raw data from the camera(s) and create the surface models of objects (e.g., faces) within a field of view of the camera, fit the surface models to a canonical meshe, store the result locally on the device and optionally transmit it to a data storage platform.

The systems and methods disclosed herein may enable the EUA to determine whether conditions are suitable for modeling prior to capture of a set of images. For example, the EUA may detect if the environment is too dark based on the camera exposure and/or the International Standards Organization (ISO) sensitivity increasing or exceeding a predetermined threshold. Additional checks may also be performed such as ensuring pixel intensities fall within acceptable ranges to avoid over-exposed areas of the image. If the system or the EUA determines that the current capture conditions are unsuitable, a message is given to the user instructing the user to improve the conditions.

In some embodiments, to prepare for capture, the EUA may generate a message instructing the user to align the user's face relative to the camera. The message may be provided in a variety of ways. In some instances, the message is provided visually. The EUA may cause presentation of the camera image on a screen of the mobile computing device along with an alignment guide. The EUA may generate a message once the face is positioned according to the guide. Face detection may be used to verify the user has correctly positioned the user's face according to the guide. In some embodiments, the message is provided audibly.

The EUA may generate and cause presentation of audio (e.g., a voice played over an audio device or speaker of the mobile computing device) including instructions indicating how to position the user's face relative to the camera. Face detection may be used to determine the current location of the user's face, which can then be used to issue instructions for proper positioning (e.g., "move closer," "move slightly to the left," or "move lower").

After the EUA detects the face is aligned, the systems and methods of the present disclosure automatically initiate the capture and modeling processes. In some instances, the capture and modeling process may be manually initiated. In either case, the systems and methods of the present disclosure, once signaled, initiate a capture component or set of components to capture a set of images and track a 3D pose of the camera relative to the user's face in real time. Based on the tracked pose and the set of images, the systems and methods of the present disclosure generate messages (e.g., visual, audio, or haptic feedback) to guide movement of the camera or the object (e.g., the user's face) into positions such that the camera observes all sides of the object. For example, where the object is the user's face, the messages may instruct movement of the face and/or image capture device to capture the face, forehead, chin, neck, and other aspects of the face. In some embodiments, the messages may instruct movement of the image capture device capturing the image of the object. For example, where the object is a car, a desk, or other object, the messages may instruct movement of the image capture device relative to the object. The EUA may provide feedback to ensure that the user has captured all relevant areas of the object (e.g., the user's face) such that a 3D model of the object can be constructed. The EUA also generates messages or alerts indicating potential problems with the scanned data capture. For example, the EUA may generate messages or alerts indicating motion blur caused by moving the camera or rotating the head too quickly.

In some embodiments, the camera of the mobile computing device that captures the set of images for 3D modeling is a rear camera. The rear camera may be positioned on a side of the mobile computing device opposite of the display device. The visual feedback (e.g., alerts and messages) displayed by the EUA may be displayed in a mirror form such that if the user is standing in front of a mirror, the user will be able to read and follow the instructions on the screen.

With reference to FIG. **1**, an example embodiment of a high-level client-server-based network architecture **100** is shown. A networked system **102**, in the example forms of a network-based model generation system, provides server-side functionality via a network **104** (e.g., the Internet or wide area network (WAN)) to one or more client devices **110**. FIG. **1** illustrates, for example, a web client **112** (e.g., a browser, such as the INTERNET EXPLORER® browser developed by Microsoft® Corporation of Redmond, Washington State), an application **114**, and a programmatic client **116** executing on client device **110**.

The client device **110** may comprise, but is not limited to, mobile phones, desktop computers, laptops, personal digital assistants (PDAs), smart phones, tablets, ultra books, netbooks, laptops, multi-processor systems, microprocessor-based or programmable consumer electronics, game consoles, set-top boxes, or any other communication device that a user may utilize to access the networked system **102**. In some embodiments, the client device **110** may comprise a display component (not shown) to display information (e.g., in the form of user interfaces). In further embodiments, the client device **110** may comprise one or more of a touch screen, accelerometer, gyroscope, camera, microphone, global positioning system (GPS) device, and so forth.

The client device **110** may be a device of a user that is used to capture images and transmit image and modeling data across a network. One or more users **106** may be a person, a machine, or other means of interacting with client device **110**. In embodiments, the user **106** is not part of the network architecture **100**, but may interact with the network architecture **100** via client device **110** or another means. For example, one or more portions of network **104** may be an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a local area network (LAN), a wireless LAN (WLAN), a WAN, a wireless WAN (WWAN), a metropolitan area network (MAN), a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a cellular telephone network, a wireless network, a WiFi network, a WiMax network, another type of network, or a combination of two or more such networks. Each of the client devices **110** may include one or more applications (also referred to as "apps") such as, but not limited to, a web browser, messaging application, electronic mail (email) application, and the like.

One or more users **106** may be a person, a machine, or other means of interacting with the client device **110**. In example embodiments, the user **106** is not part of the network architecture **100**, but may interact with the network architecture **100** via the client device **110** or other means. For instance, the user provides input (e.g., touch screen input or alphanumeric input) to the client device **110** and the input is communicated to the networked system **102** via the network **104**. In this instance, the networked system **102**, in response to receiving the input from the user, communicates information to the client device **110** via the network **104** to be presented to the user. In this way, the user can interact with the networked system **102** using the client device **110**.

An application program interface (API) server **120** and a web server **122** are coupled to, and provide programmatic and web interfaces respectively to, one or more application servers **140**. The application servers **140** may host one or more publication systems **142** and model generation systems **150**, each of which may comprise one or more components or applications and each of which may be embodied as hardware, software, firmware, or any combination thereof. The application servers **140** are, in turn, shown to be coupled to one or more database servers **124** that facilitate access to one or more information storage repositories or database(s) **126**. In an example embodiment, the databases **126** are storage devices that store information to be posted (e.g., publications or listings) to the publication system **142**. The databases **126** may also store object data, historical data, and 3D model data in accordance with example embodiments.

In some instances, the database and the database server may act as a data storage platform for 3D models generated within the client device **110**. The database server **124** may store information about each end user (e.g., the user **106**) who has uploaded a model to the database **126**. Information captured and retained about each user may include, but is not limited to, name, email address, password, and any additional location or identification data that may be requested by the database server **124**. Each model stored in the database server **124** or the database **126** may be associated with the end user **106** who created it, or associated with any third-party who has been granted access rights by the end user **106** creator. Metadata, such as, but not limited to, the number and originators of downloads, is also captured and maintained for each face model for the purposes of business and system analytics.

In some embodiments, the API server **120** includes a third party data access interface (TPDAI). The TPDAI is an API protocol enabling authorized third party programs and systems to access models in the database server **124** or the database **126** on behalf of the user **106**. The TPDAI enables third party programs and systems to authenticate against the user's **106** access credentials to download or otherwise access the model. TPDAI requests may also contain a valid access token which enables the database server **124** to ensure that the request originated from an authorized user **106** of the database server **124**. The valid access token also permits the End-User Application to track the volume of usage per third party system, as well as permitting additional tracking and management operations. In response to requests from third party programs or systems, the model data transmitted to third party programs or systems may contain all the elements to import, visualize, or manipulate the model in software programs or physical components and computing systems that contain or display 3D graphics.

Additionally, a third party application **132**, executing on third party server(s) **130**, is shown as having programmatic access to the networked system **102** via the programmatic interface provided by the API server **120**. For example, the third party application **132**, utilizing information retrieved from the networked system **102**, supports one or more features or functions on a website hosted by the third party.

The publication system **142** may provide a number of publication, archival, and data storage functions and services to users **106** that access the networked system **102**. For example, the publication system **142** may gather, publish, and store object data, 3D model data, 2.5 dimensional model data, and other data relating to generated models and applications of the models to one or more platforms or programs. The publication system **142** may publish the object data, image data, and model data to an internal database or publicly available database to enable generation of 3D models based on the object data, the image data, and movement data. In some embodiments, the publication system **142** accesses one or more third party servers or databases (e.g., the third party server **130**) to retrieve, modify, and provision the object data within the database **126**.

The model generation system **150** may provide functionality operable to perform various model generation and manipulation functions, as well as functions for generating graphical representations of objects, instructions, image and model editing effects, and model modification. For example, the model generation system **150** generates 3D models of objects, body parts, or scenes based on image data provided by an image capture device associated with or coupled to the client device **110**. The 3D models may be generated based on movement of the object or face, or movement of the image capture device. In some example embodiments, the model generation system **150** communicates with the publication systems **142** to access or provide 3D modeling data for use by third party programs or systems.

Further, while the client-server-based network architecture **100** shown in FIG. **1** employs a client-server architecture, the present inventive subject matter is of course not limited to such an architecture, and could equally well find application in a distributed, or peer-to-peer, architecture system, for example. The various publication system **142** and model generation system **150** could also be implemented as standalone software programs, which do not necessarily have networking capabilities.

The web client **112** may access the various publication and model generation systems **142** and **150** via the web interface supported by the web server **122**. Similarly, the programmatic client **116** accesses the various services and functions provided by the publication and model generation systems **142** and **150** via the programmatic interface provided by the API server **120**.

Additionally, a third party application(s) **132**, executing on a third party server(s) **130**, is shown as having programmatic access to the networked system **102** via the programmatic interface provided by the API server **114**. For example, the third party application **132**, utilizing information retrieved from the networked system **102**, may support one or more features or functions on a website hosted by the third party. The third party website may, for example, provide one or more promotional, marketplace, data repository, company interaction, or object tracking functions that are supported by the relevant applications of the networked system **102**.

FIG. **2** is a block diagram illustrating components of the model generation system **150**, according to some example embodiments. The model generation system **150** is shown as including a presentation component **210**, a detection component **220**, a notification component **230**, a position component **240**, a modeling component **250**, and a model review component **260** all configured to communicate with one another (e.g., via a bus, shared memory, or a switch). Any one or more of the components described herein may be implemented using hardware (e.g., one or more processors of a machine) or a combination of hardware and software. For example, any component described herein may configure a processor (e.g., among one or more processors of a machine) to perform operations for which that component is designed. Moreover, any two or more of these components may be combined into a single component, and the functions described herein for a single component may be subdivided among multiple components.

The presentation component **210** causes presentation of the user interface and user interface elements generated by the detection component **220**, the notification component **230**, the position component **240**, and the model review component **260**. The presentation component **210** also causes presentation of 3D models generated by the modeling component **250**. In some embodiments, the presentation component **210** causes presentation by rendering the user interfaces and user interface elements at the client device **110** via a display device. The presentation component **210** may operate in cooperation with one or more of the other components described herein.

The detection component **220** detects objects of interest within the field of view of an image capture device associated with the client device **110**. In some instances, the detection component **220** detects objects of interest and positioning of objects of interest within a graphical user interface element presented on a display device.

The notification component **230** generates user interface elements, selectable user interface elements, and instruction sets based on interactions, selections, movements, and operations received by the client device **110**. In some embodiments, the notification component **230** determines an appropriate user interface element, instruction set, or combination thereof based on operations and completion status of operations being performed by one or more of the other components described herein.

The position component **240** detects changes in position of the object of interest once the object of interest is appropriately positioned within the field of view of the image capture device. The position component **240** may cooperate with the notification component **230** to direct movement of the object of interest with respect to the client device **110**, or the client device **110** with respect to the object of interest.

The modeling component **250** generates 3D models from sets of image frames or video received from the image capture device and movement of the object of interest or the image capture device corresponding with the instructions generated by the notification component **230**. In some instances, the modeling component **250** generates the 3D model along with an image incorporating the 3D model.

The model review component **260** may cooperate with the presentation component **210** to generate user interface elements representing possible modifications to the 3D model. In some instances, the model review component **260** receives modification input from a user interface device and causes the modeling component **250** to generate a modified model based on the input.

FIG. **3** is a flowchart of operations of the model generation system **150** in performing a method **300** of generating 3D models within a graphical user interface, according to some example embodiments. Operations in the method **300** may be performed by the model generation system **150**, using components described herein.

In some instances, prior to initiation of the method **300**, the model generation system **150** may receive an initiation instruction. The model generation system **150** may initiate the end-user application on one or more image capture devices associated with a mobile computing device (e.g., the client device **110**), mobile device, tablet, internet computer, mobile phone, or other device having the capability to capture video. The model generation system **150** receives an initiation selection, which starts a new capture session. Initiation of the capture session may cause the image capture device or image capture devices to begin video capture or enable video capture to begin by accessing one or more modules or components associated with the image capture device.

In operation **310**, the presentation component **210** causes presentation of a graphical user interface frame encompassing a graphical rendering of a field of view of an image capture device of a mobile computing device. The graphical user interface frame may be generated as an overlay presented over a rendering of contents of the field of view of the image capture device of the mobile computing device. For example, as shown in FIG. **4**A, a graphical user interface frame **410** may include one or more selectable user interface elements **420** configured to cause a selection between two or more image capture devices of the mobile computing device. The graphical user interface frame may also include notification interface elements **430** operating as messages, alerts, or instructions for operation of the EUA.

As shown in FIG. **4**A, the graphical user interface frame **410** may be configured with a visible framing element **440** sized and shaped based on the field of view of the image capture device and an expected object. In FIG. **4**, the visible framing element **440** is sized and shaped to encompass a face. The visible framing element **440** is represented as an oval positioned within the field of view of the image capture device. The oval may be sized such that a face positioned within the oval and occupying a predetermined portion of the oval is positioned properly for scanning and generation of a 3D model. Although the visible framing element is shown as an oval, it should be understood that the visible framing element **440** may be other suitable shapes (e.g., a square, a rectangle, a circle, or a polygon) configured based on dimensions (e.g., a size and shape) of the object to be modeled.

The one or more selectable user interface elements **420** may be positioned on a portion of the display outside of the visible framing element **440**. As shown in FIG. **4**A, the one or more selectable user interface elements **420** may be positioned at a bottom portion of the display below the visible framing element **440** and a rendering of the field of view of the image capture device. The one or more selectable user interface elements **420** may be a single user interface element, the selection of which causes the mobile computing device to toggle between a first image capture device and a second image capture device.

In some instances, toggling between the first image capture device and the second image capture device may cause the presentation component **210** to render changes in the visible framing element **440**. For example, as shown in FIGS. **4**A and **4**B, the selectable user interface element **420** may be selectable to toggle between the first image capture device (e.g., a rear facing camera) for capture and modeling of a scene or objects in a wide field of view and the second image capture device (e.g., a front facing camera) for capture and modeling of a face. When the selectable user interface element **420** is toggled to the first image capture device for modeling a face, as shown in FIG. **4**A, the visible framing element **440** (e.g., framing element **440**A) may be an oval or other suitable shape for framing a face depicted within the field of view. As shown in FIG. **4**B, when the selectable user interface element **420** is toggled to the second image capture device for modeling a scene, the visible framing element **440** (e.g., framing element **440**B) may be a rectangle and encompass a different portion of the field of view than the visible framing element **440**A.

The one or more selectable user interface elements **420** may include a set of user interface elements. The set of user interface elements may be selectable to configure one or more aspects of image capture of the EUA. For example, a user interface element may select the image capture device, an image capture characteristic (e.g., a flash), an image import (e.g., retrieving a previously captured image), or a cancellation. Selection of a cancellation element may cease an image capture mode and cause the presentation component **210** to render a menu or other graphical user interface screen.

The notification interface element **430** may include instructions for interacting with one or more of the image capture device, the visible framing element **440**, or the EUA. For example, as shown in FIG. **4**A, the notification interface element **430** instructs the user to "Fit face inside area below" such that the face is positioned within the visible framing element **440**.

In operation **320**, the detection component **220** detects an object of interest within the graphical user interface frame and the field of view of the image capture device. For example, where the EUA is in a mode for modeling a face, the detection component **220** may detect a face within the graphical user interface frame and the field of view. In some embodiments, the detection component **220** is configured with predetermined detection algorithms associated with a given capture mode toggled by the selectable user interface element **420**. For example, where the selectable user interface element **420** is toggled to the second position toward the face, the detection component **220** may be configured to run a face detection algorithm such as a Viola-Jones detection algorithm. In some instances, the detection component **220** dynamically selects a detection algorithm upon initiation of the operation **320**. To dynamically select a detection algorithm, the detection component may be configured with a set of object detection algorithms. For example, the object detection algorithms may include edge detection algorithms, point detection algorithms, shape detection algorithms, object recognition algorithms, face detection algorithms, or any other suitable algorithms or set of processes to identify objects of interest within a field of view. The detection component **220** may run one or more of the object detection algorithms until an object type is identified for the object within the field of view. For example, the detection component **220** may step through the object detection algorithms in an predetermined or random order until an object detection algorithm of the set of object detection algorithms identifies the type (e.g., a classification) of the object.

The detection component **220** may detect the object of interest using one or more detection methods. For example, the detection component **220** may use one or more edge detection operations, point detection operations, or facial detection operations. The object detection operations may be selected based on the position of the selectable user interface element **420**. Where the selectable user interface element is positioned for capturing and modeling a scene, the detection component **220** may select point detection operations or edge detection operations for object recognition. Where the selectable user interface element is positioned for capturing and modeling a face, the detection component **220** may select and employ facial detection operations to detect the face within the field of view.

In operation **330**, the notification component **230** generates a movement instruction directing movement of the object within the field of view of the image capture device. Where the object to be modeled is a scene, the notification component **230** may generate a movement instruction directing movement of the image capture device or the mobile computing device. In instances where the object to be modeled is a face, the notification component **230** generates a movement instruction directing movement of the face.

As shown in FIGS. **4**A, **5**, and **6**, where the detection component **220** detects a face, the notification component **230** may initially generate movement elements including movement instructions directing movements to position the face within the visible framing element. For example, the notification component **230** may initially generate a first movement element including an instruction to "Move your face closer." as shown in FIG. **5**. Based on the detection component **220** detecting movement of the face within the field of view but without properly positioning the face for scanning and modeling, the notification component **230** may alternate from FIG. **5** to FIG. **4**A, changing the first movement element and the movement instruction to a second movement element. As shown in FIG. **4**A, the second movement element includes an instruction to "Fit face inside area below."

Once the detection component **220** detects the face within the visible framing element **440**, the notification component **230** may generate a third movement element. The third movement element may be a user element configured as a focus element. The focus element is configured and positioned to direct a gaze of the eyes. The focus element may be positioned proximate to the image capture device of the mobile computing device. For example as shown, the focus element is positioned in a graphical user interface on the display device and below the image capture device of the mobile computing device. In some instances, the third movement element includes an instruction to "Hold still," as shown in FIG. **6**. In addition to the third movement element, the notification component **230** may generate a pose element. In FIG. **6**, the pose element is separate from the third movement element and may direct a movement or pose distinct from the instruction of the third movement element. As shown, the pose element includes an instruction to "Watch the dot" and contains a directional element visually directing the instructed pose. The pose element instruction may instruct the user to affix a gaze on the focus element to align the eyes to a position proximate to the image capture device. When the gaze is directed at the focus element and the focus element moves with the face, the model generation system **150** may capture images and generate a 3D model which center the pupil and iris of the eyes.

In operation **340**, the position component **240** detects a first change in position of the object (e.g., a face) within the field of view of the image capture device. Upon detecting the first change in position of the object, the position component **240** causes the image capture device to capture image data for the first change in position. In some instances, where sensor data is detected in addition to the image data and indicates the first change in position, the position component **240** may capture the sensor data.

In some embodiments, the input data may include the raw image frames obtained from the image capture device as well as sensor data, such as accelerometer data and gyroscope data, from sensors associated with the mobile computing device. To provide appropriate input data for the subsequent 3D reconstruction (e.g., modeling) stages, the position component **240** and the detection component **220** specify a set of target 3D poses to be observed by the camera. During capture, the detection component **220** and the position component **240** monitor the current 3D pose of the camera and track the 3D pose of the image capture device relative to the object.

In some embodiments, the first change in position of the face is an expected position change. The expected position change may include a first initial position and a first final position. The first change in position may also include a first set of intermediate positions. Each of the first initial position, the first set of intermediate positions, and the first final position may be associated with a first side of a face, where the model generation system **150** is configured to model faces captured by the image capture device.

Upon detection of the face within the visible framing element **440**, the detection component **220** may initiate image capture and modeling operations. As shown in FIG. **7**, initiation of the image capture operations may cause the notification component **230** to generate a position element **710** including instructions **720** for a change in position of the face (e.g., the object within the field of view). In FIG. **7**, the position element **710** may be a first position element **730** instructing a first change in position. The first position element **730** in may include a first start position **740** and a first end position **750**. For example, the position element may include instructions **720** to "Slowly turn your head to the right."

As shown in FIG. **8**, during the first change in position, detected in operation **340**, the position component **240** continually monitors (e.g., tracks) the motion of the object (e.g., face) within the field of view. The position component **240** may pass a portion of data representing the motion to the notification component **230**. The notification component **230** may continually modify the graphical user interface in real time based on the motion data. In FIG. **8**, the notification component **230** continually adjusts or modifies the position element **710**. The notification component **230** may modify the position element **710** by moving the first position element **730** relative to a current position of the object within the field of view and a distance of travel detected for the object. The first position element **730** may move a distance between the first start position **740** and the first end position **750**. The location of the first position element **730** along the distance may be proportional to an amount of motion detected in the object between a starting position and an expected ending position.

In operation **350**, the position component **240** detects a second change in position of the object (e.g., a face) within the field of view of the image capture device. The second change in position of the object may be in a trajectory similar to or the same as a trajectory of the first change in position of the object, described in operation **340**. Upon detecting the second change in position, the position component **240** causes the image capture device to capture image data indicative of the second change in position. In some instances, as described above, the position component **240** captures sensor data indicative of the second change in position in addition to the image data.

In some instances, the second change in position of the face is an expected position change. The expected position change may include a second initial position and a second final position. In some embodiments, the second change in position includes a second set of intermediate positions. Each of the second initial position, the second set of intermediate positions, and the second final position may be associated with a second side of a face, where the model generation system **150** is configured to model faces captured by the image capture device.

As shown in FIG. **9-11**, upon completion of the first change in position, the notification component **230** generates a position element **910** including instructions **920** for the second change in position of the object (e.g., the face). In FIG. **9**, the position element **910** is a second position element **930** which includes a second start position **940** and a second end position **950**. As shown, the position element **910** may include instructions **920** to "Slowly turn your head to the left," indicating an anticipated direction of the second change in position. In some instances, the second start position **940** may be positioned at or proximate to the first end position **750**, such that the first change in position and the second change in position are linked to form a fluid motion. As shown in FIGS. **9-11**, the notification component **230** may monitor the second change in position detected by the position component **240** and continually modify the position element **910** to proportionally represent the position of the object (e.g., the face) between the initial position of the second change in position and an expected end of the second change in position.

Although described as capturing image and sensor data in response to the first change in position and the second change in position, it should be understood that the position component **240** may capture a stream of images (e.g., a set of image frames) and sensor data representative of the first change in position, the second change in position, and movement between the first change in position and the second change in position. In some instances, as will be explained in more detail below, the first change in position, the second change in position, and one or more intermediate changes in position (e.g., along the first change in position and the second change in position) may be identified as key frames within a stream of images used to generate a 3D model of the object.

In some embodiments, the position component **240** detects the first change in position and the second change in position in a single sweeping motion. For example, where the model generation system **150** is capturing and modeling a face, the face may initially be positioned such that a profile of the face is within the field of view. In some instances, the position component **240** detects a single change in position as a rotation across two or more planes. For example, the single change in position may be a rotation of the face exposing a right profile, a left profile, an uppermost part of a forehead, and an underside of a chin or jaw. The position component **240**, upon a change in position, may perform the operation **340** described above. As the face passes a centerline, the position component **240** may perform the operation **350**. In some embodiments, the position component **240** detects more than two changes in position. For example, the position component **240** may detect a first change in position of a face rotating right from a center position, a second change in position of the face rotating left from a center position or from a right profile position, a third change in position of the face rotating downward from a center position, and a fourth change in position of the face rotating upward from a center position or from a downward position.

Although described with respect to capturing data for an object of interest in the form of a face, it should be understood that the present methods and systems enable capture and dimensional modeling of scenes and objects other than faces or human body parts.

In operation **360**, the modeling component **250** generates a 3D model of the object (e.g., the face). The 3D model may be generated based on the image data captured from the first change in position and the second change in position. As will be explained below in more detail, the 3D model may be generated based on individual key frames and trajectories for tracking points detected on or around the object.

After completion of the second change in position, the notification component **230** generates a processing element. The processing element may be presented along with an obscured representation of the ending position of the second change in position. The processing element may be rendered as a representation of the modeling component **250** generating the 3D model of the object. The presentation component **210** may cause presentation of the processing element (e.g., by rendering an animated point of light traveling around a circle, an hourglass, or an element sweeping across a portion of the display device) for a period of time corresponding to the generation of the 3D model.

Once the modeling component **250** generates the 3D model of the object, as shown in FIGS. **12** and **13**, the presentation component **210** may render the 3D model in an isolated interface **1210**. In some embodiments, the isolated interface **1210** includes the 3D model **1220** in an interactive representation without a background captured within the image data. The interactive representation may be linked to the one or more sensors of the mobile computing device to enable interaction with the 3D model **1220**. As shown in FIGS. **12** and **13**, movement of the mobile computing device is detected within a motion sensor (e.g., a gyroscope or an accelerometer) and causes representative manipulation of the 3D model **1220**. For example, moving a left side of the mobile computing device may be translated by the motion sensor and the presentation component **210** into a rotation of the 3D model **1220** to expose the left side of the 3D model **1220** relative to the viewer. Moving a right side, upper side, or lower side of the mobile computing device may be translated by the motion sensor and the presentation component **210** into a rotation of the 3D model **1220** to expose a right side, a top side, or a bottom side, respectively, of the 3D model **1220** relative to the viewer.

In some embodiments, the presentation of the 3D model in FIGS. **12** and **13** may be initiated by a model review component **260**, in response to the 3D model being generated. The model review component **260** may enable review of the 3D model that resulted from a face capture session. In some instances, the model review component **260** generates one or more user interface elements to manipulate, modify, and interact with the 3D model. The modeling component **250** may produce multiple models in a scan and capture session. Each captured and created model may be stored in a digital storage device locally resident on the device (e.g., a non-transitory processor readable storage medium associated with the mobile computing device). A user may choose to discard a given 3D model or transmit it from the local digital storage to a data storage platform, located external to the scan capture device, for later retrieval and/or deployment to other applications, mobile devices, or computing systems.

The model review component **260**, in conjunction with the presentation component **210** may cause presentation of a review interface **1410**, as shown in FIGS. **14** and **15**. The review interface **1410** may include one or more review elements **1420** (e.g., first, second, and third review elements **1430**, **1440**, and **1450**). The one or more review elements **1420** enable modification of the 3D model within a set of predefined modification options. As shown in FIGS. **14** and **15**, the first review element **1430** enables selection of one or more color filters, color effects, color temperature filters, and other filters, effects, and color value adjustments configured to modify one or more of a color, a sharpness, a tint, a saturation, or a hue of the 3D model. In some instances, selection of the first review element **1430** causes the model review component **260** and the presentation component **210** to generate and cause presentation of effect elements. The effect elements may include a thumbnail or preview of the 3D model rendered with the effect corresponding to a specified interface element.

As shown in FIG. **15**, selection of the second review element **1440** causes the model review component **260** and the presentation component **210** to generate a depth adjustment element **1510**. Movement of the depth adjustment element **1510** causes the model review component **260** and the modeling component **250** to modify a depth of the 3D model. For example, as shown in FIG. **15**, movement of the depth adjustment element **1510** to the left, with respect to the user, causes the modeling component **250** and the presentation component **210** to render the 3D model in a comparatively shallower depth. Movement of the depth adjustment element **1510** to the right, with respect to the user, causes the modeling component **250** and the presentation component **210** to render the 3D model in a comparatively deeper depth.

Selection of the third review element **1450** enables adjustment of an apparent depth of field of the 3D model by enabling modification of a point of focus within a rendered image containing the 3D model. In some embodiments, upon selection of the third review element **1450**, the notification component **230** and the presentation component **210** generates and causes presentation of an instruction to interact with the rendered image and 3D model. For example, the instruction may indicate that a modification of the point of focus is performed by tapping on a touchscreen interface at a point of desired focus. Upon receiving a selection of a portion of the rendered image and 3D model, the model review component **260** and the modeling component **250** modify a level of focus of the selected point and a portion of the rendered image and 3D model encompassing the selected point within a predetermined proximity.

FIG. **16** is a flow chart of operations of the model generation system **150** in performing operations of a method **1600** of generating 3D models within a graphical user interface, according to some example embodiments. The operations depicted in FIG. **16** may be performed by the model generation system **150**, using components described herein. As shown in FIG. **16**, in some embodiments, the method **1600** may be performed as a part of or sub-operations of the method **300**, described above.

In operation **1610**, the detection component **220** identifies a set of facial tracking points on the face within the field of view of the image capture device. In some embodiments, the identification of the set of facial tracking points may be a rough face detection prior to image capture. The rough face detection is performed to identify that the object (e.g., the face) is properly aligned within the field of view. The set of facial tracking points may be pixels in one or more of the images from the image capture device which are suitable for tracking over time. The operation **1610**, or a similar process, may be performed each time a reference key frame is updated during capture to generate these points for each reference key frame.

In some instances, the set of facial tracking points are feature points of a face such as points defining a shape of the face, an eyebrow, a mouth, a nose, an eye, and other suitable feature points. The set of facial tracking points may initially be two dimensional interest points detected on the user's face in a reference image. The interest points may be detected using an interest point detection algorithm. In some instances, the interest points are detected using standard interest point detection algorithms such as Features from Accelerated Segment Test (FAST), Adaptive and Generic Corner Detection Based on the Accelerated Segment Test (AGAST), Harris, Shi-Tomasi. and others. In some embodiments, to establish a more even distribution of interest points, the area of the field of view or the image which is expected to contain the face (e.g., the portion of the field of view or the image within the visible framing element) may be divided into a grid. An interest point may be determined for each grid cell of the grid according to an interest point scoring function such as Harris. Shi-Tomasi or others. The process of determining interest points for grid cells may be repeated at different scales for the image data in order to identify multiple scale interest points.

In some embodiments, in response to detecting one or more of the first change in position, in the operation **340**, and the second change in position, in operation **350**, the notification component **230** generates graphical representations of the set of facial tracking points on the face within the graphical user interface frame. As shown in FIG. **7**, the presentation component **210** causes presentation of the graphical representations of the set of facial tracking points on the face for a duration of detecting the first change in position and the second change in position.

In operation **1620**, the position component **240** identifies a first key frame where the set of facial tracking points has a set of first positions. When the face is sufficiently close to a target pose, the detection component **220** and the position component **240** records the information associated with the camera frame as a key frame for later processing. A key frame consists of the camera image along with any sensor data such as that from an accelerometer and/or gyroscope associated with the mobile scan data capture device, the estimated 3D pose of the camera, and a set of 2D measurements of interest points on the user's face.

In operation **1630**, the position component **240** determines a change in position of one or more facial tracking points from the set of first positions. After the interest points are identified, the position component **240** may track the two dimensional position of each interest point over time in subsequent image frames received from the image capture device. This tracking by the position component **240** may be performed in response to detecting the change in position of the one or more facial tracking points or in response to the first change in position or the second change in position, as described in operations **340** and **350**, respectively. In some embodiments, the position component **240** may track the two dimensional position of each interest point using a suitable tracking algorithm such as Kanade-Lucas-Tomasi tracking.

In some embodiments, the operation **1630**, is performed by one or more sub-operations. In operation **1632**, in response to initiation of the change in position of the one or more facial tracking points, the position component **240** identifies a trajectory for each of the one or more facial tracking points. The trajectory may be identified as a two dimensional vector extending away from the initial position of a given facial tracking point. Where the initial position of the facial tracking points is a key frame, the vector may extend between the initial position and the subsequent position indicating a direction of travel over time.

As the object moves, the trajectories are tracked and grow in length. In embodiments where the object is a face, as the face is rotated with respect to the image capture device, the position component **240** tracks the trajectories of the one or more facial tracking points as the trajectories increase in length. Based on tracking the one or more facial tracking points across multiple image frames, the trajectories may grow with each successive image frame with respect to the initial image frame from the image data captured by the image capture device.

In operation **1634**, the position component **240** determines an average length of the trajectories of the one or more facial tracking points. The average length of the trajectories may be determined based on a distance of the vector extending between the initial position and the subsequent position for each of the one or more facial tracking points. The distances associated with each of the one or more facial tracking points may then be averaged across the one or more facial tracking points. Averaging the distances for the one or more facial tracking points may be performed by calculating the median trajectory length to provide robustness to erroneous tracks.

In operation **1636**, the position component **240** determines the average length exceeds a trajectory threshold. Once the average length of the trajectories exceeds the trajectory threshold in a direction indicated by the instructions of the position element, described above, the position component **240** may identify a target 3D pose for the image capture device and record a key frame, as described below.

In some instances, the trajectory threshold may be a predetermined segment of an average distance traveled by facial tracking points between an initial position and an expected final position. The trajectory threshold may be determined prior to initiation of image capture and modeling operations. In some instances, the trajectory threshold may be determined during a configuration process of the model generation system **150**. In some embodiments, the trajectory threshold may be heuristically determined based on the object being modeled. In some instances, the trajectory threshold is determined as a portion of the image width. For example, the trajectory threshold may be a distance equal to between 0.5% and 10% of the image width or the field of view of the image capture device.

In operation **1640**, based on the change in position, the position component **240** identifies a second key frame where the one or more facial tracking points have a second position. The second key frame may be determined based on the one or more facial tracking points being within a predetermined proximity of an expected position (e.g., the second position). In embodiments where the position component **240** determines the average length exceeds the trajectory threshold, as in operation **1636**, the second key frame may be identified based on the determination that the average length exceeds the trajectory threshold.

In some embodiments, the one or more facial tracking points having trajectories which persist (e.g., extend) from the initial key frame to the second key frame (e.g., a new key frame) are used to record measurements in both the initial key frame and the second key frame. The persistent measurements may specify the observed two dimensional location of a particular interest point in a key frame. Using assumed 3D poses of the image capture device for the first two key frames, an initial estimate of the 3D positions of the interest points is computed by triangulating the two measurements associated with each interest point.

Using the initial estimates of key frame poses and 3D interest point positions, the position component **240** may perform a bundle adjustment in order to refine the pose of the second key frame as well as the 3D positions of the interest points. During bundle adjustment, a robust nonlinear least squares optimization may be performed to jointly optimize 3D key frame poses and 3D interest point positions in a manner which theoretically minimizes reprojection error of the interest points in the key frames. Reprojection error may be defined as a distance between the two dimensional projected positions of interest points in key frames and the actual two dimensional measurements which were observed.

FIG. **17** is a flow chart of operations of the model generation system **150** in performing operations of a method **1700** of generating and manipulating 3D models within a graphical user interface, according to some example embodiments. The operations depicted in FIG. **17** may be performed by the model generation system **150**, using components described herein. In some embodiments, as shown in FIG. **17**, the method **1700** may be performed as part of or as sub-operations of the method **300**, described above.

In operation **1710**, the position component **240** identifies one or more subsequent key frames based on one or more changes in position of the one or more facial tracking points along the trajectories. The one or more subsequent key frames may be determined similarly to or the same as the first key frame and the second key frame described with respect to FIG. **16**. In some embodiments, the number of subsequent key frames identified by the position component **240** may be predetermined based on the object. For example, where the object is a face, the face may have an expected range of motion (e.g., a turn of the neck) corresponding to the distance between an initial position and a final position for the set of facial tracking points. The distance between the initial position and the final position may be divided equally to determine the number of subsequent key frames for a given side of the face.

In some instances, the newest key frame (e.g., the second key frame or a subsequent key frame most recently generated) may be used as a current reference key frame. The position component **240** initializes tracks for each existing measurement in the reference key frame. New tracks may also be initialized using the same interest point detection method described above. The new tracks may be initialized in interest points a predetermined distance apart from existing tracks.

In operation **1720**, based on the first key frame, the second key frame, and the one or more subsequent key frames, the position component **240** generates a set of relative 3D position estimates for the mobile computing device. The set of relative position estimates may indicate a relative position of the mobile computing device with respect to the object being modeled (e.g., the face). The position component **240** may generate a relative position estimate of the set of relative position estimates for each key frame (e.g., the first key frame, the second key frame, and the one or more subsequent key frames). The set of relative position estimates may enable identification of interest points with known 3D positions which are not being tracked in a current image frame using the 3D camera pose estimate from the previous frame. This discover operation may enable recapturing interest points lost between two frames.

In some instances, the set of relative position estimates may be used to identify key frames. In these instances, a relative position estimate for a current frame may be compared against the next target relative position estimate. When the relative position estimate enters within a predetermined proximity to the next target relative position estimate, the position component **240** identifies a new key frame and records the new key frame using the current image frame along with the relative position estimate proximate to the target relative position estimate. Measurements may be recorded for each tracked interest point within the new key frame. For interest points which did not previously have 3D positions (e.g., newly identified interest points in the most recent key frame), the tracks (e.g., a trajectory for each new interest point) may be filtered to ensure satisfaction of an epipolar constraint between the reference key frame and the new key frame. Tracks which satisfy the epipolar constraint may be used to create measurements in both the reference key frame (e.g., the previously identified key frame) and the new key frame. The 3D positions of the associated interest points may be initialized using triangulation between the measurements in the reference key frame and the new key frame.

In some embodiments, after identifying a new key frame, one or more adjustment processes may be performed on the key frames identified prior to and including the new key frame. The one or more adjustment processes may be a bundle adjustment, as described above. The bundle adjustment may improve or refine estimates of key frame relative 3D positions and the 3D positions of interest points. Each time a new key frame is recorded, a bundle adjustment may be performed to jointly refine the estimates of all key frame poses and 3D interest point positions prior to and including the new key frame.

In operation **1730**, based on the first key frame, the second key frame, the one or more subsequent key frames, and the set of relative position estimates, the modeling component **250** generates a set of depth maps. In some embodiments, the set of relative depth maps includes a depth map for each key frame. Given the set of key frames and the 3D interest points (e.g., facial tracking points and trajectories), the modeling component **250** generates 2.5 dimensional depth maps for one or more of the key frames using multi-view stereo techniques.

In some embodiments, depth map estimation is performed by plane-sweep stereo. In these embodiments, photo consistency between the image frame of the reference key frame and one or more other image frames of one or more other key frames is computed at a predetermined number of discrete depths for each pixel in the depth map. The final depth map may be produced by selecting the depth for each depth map pixel which produces the best photo consistency between views.

In some instances, prior to generating the set of depth maps, the modeling component **250** preprocesses the image frames for the key frames. Preprocessing may generate a representation of the image frames which encode both texture and luminance. For a given pixel, the modeling component **250** samples a 5×5 patch around the pixel. The modeling component **250** computes a 24-bit binary signature by comparing the luminance of each non-central pixel to a mean luminance of the patch. The comparison of the luminance and the mean luminance is combined with the 8-bit luminance of the central pixel to give a 32-bit value which may be stored in a red, green, blue, alpha (RGBA) texture and sampled with a single texture lookup on a graphics processing unit (GPU). The modeling component **250** may calculate photo consistency between two such values by combining a Hamming distance on the binary signature and a Euclidian distance on the luminance.

Photo consistency values may be pooled from neighboring pixels in order to generate robust photo consistency values. For example, the modeling component **250** may pool photo consistency values from neighboring pixels within a 3×3 patch at a given depth. The robust photo consistency values may be determined during a plane-sweep. In some embodiments, the modeling component **250** generates a two pass plane-sweep stereo. In these instances, the modeling component **250** generates the depth map using a first pass plane-sweep, as described above. The first pass may then be used as a starting point for a subsequent plane-sweep by the modeling component **250** over a smaller depth range around the previous generated depth map. The subsequent plane-sweep may modify the depth range for each pixel in the depth map.

In some embodiments, the measurements of the 3D interest points in a given key frame may be used to guide depth map generation. The modeling component **250** may provide initialization or constraints for selected regions during depth map generation. The depth maps may also be post-processed to reduce noise. Post-processing by the modeling component **250** may include consistency checks between key frames. Post-processing operations of the modeling component **250** may further include median filtering, bilateral filtering, total variation based on de-noising, and conditional random field labeling between key frames forming the depth map values.

In some instances, the operation **1730** includes a set of sub-operations. The sub-operations of the operation **1730** may be performed for each depth map generated by the modeling component **250** in generating the set of depth maps. In operation **1732**, the modeling component **250** generates a first depth map having a first resolution.

In operation **1734**, the modeling component **250** generates a second depth map having a second resolution. In some instances, the second resolution is a higher resolution than the first resolution of the first depth map. In some embodiments, the modeling component **250** may create more than two depth maps. The modeling component **250** may create depth maps with increasing higher resolution a predetermined number of times, until a predetermined resolution is reached, or any number of iterations for any suitable resolution.

FIG. **18** is a flow chart of operations of the model generation system **150** in performing operations of a method **1800** of generating and manipulating 3D models within a graphical user interface, according to some example embodiments. The operations depicted in FIG. **18** may be performed by the model generation system **150**, using components described herein. In some embodiments, as shown in FIG. **18**, the method **1800** may be performed as part of or as sub-operations of the method **1700**, described above.

In operation **1810**, the modeling component **250** fuses the set of depth maps to generate the 3D model of the face. In some instances, the modeling component **250** combines 2.5 dimensional depth maps into a single 3D surface model of the object (e.g., the face).

In operation **1820**, the modeling component **250** defines a volumetric 3D grid for the 3D model of the face. In combining depth maps, the modeling component **250** defines a truncated signed distance function (TSDF) over the volumetric 3D grid. Although described in separate operations, in some instances, the operations **1810** and **1820** are performed in a single operations such that the volumetric 3D grid with TSDF is a single approach for fusing depth maps into a single 3D model.

In operation **1830**, the modeling component **250** represents a 3D surface of the 3D model within the volumetric 3D grid. Each element in the grid (e.g., a voxel) is identified as inside or outside of the 3D surface and stored as a scalar value between −1 and 1. The sign of the value defines whether the voxel is inside or outside the 3D surface. The 3D surface may be defined implicitly by a boundary between positive and negative values.

In some embodiments, depth maps generated for each key frame may provide an estimate of the surface of the 3D model. The modeling component **250** may convert the depth maps into a view specific TSDF over the volumetric 3D grid. The TSDF of each depth map may be aggregated to accumulate a histogram of TSDF values at each voxel in the volumetric 3D grid. The histogram of TSDF values acts as a summarization of the estimates according to the generated depth maps. The modeling component **250** may perform a theoretical optimization on the histogram of TSDF values to estimate a single TSDF value at each voxel which takes into account both the histogram data and a regularization strategy to encourage smoothness. In some embodiments, the modeling component **250** uses an LI data term and total variation regularization, resulting in a surface which is robust to noisy depth map data. Further, the surface is smooth and minimizes small isolated surface regions. This optimization approach is also suitable for GPU implementation, making the optimization action efficient in practice. In some instances, the surface defined by the optimized TSDF may be converted into a polygonal surface mesh using an implicit surface polygonization algorithm such as marching cubes or Bloomenthal's method.

In some instances the depth maps may be dense depth maps and represent a 3D surface of the model as a mesh. The 3D surface may be constructed using Poisson surface reconstruction operations.

FIG. **19** is a flow chart of operations of the model generation system **150** in performing operations of a method **1900** of generating and manipulating 3D models within a graphical user interface, according to some example embodiments. The operations depicted in FIG. **19** may be performed by the model generation system **150**, using components described herein. In some embodiments, as shown in FIG. **19**, the method **1900** may be performed as part of or as sub-operations of the method **1800**, described above.

In operation **1910**, the modeling component **250** identifies a facial mesh. The facial mesh may include a set of polygons and a set of vertices connecting the set of polygons. The set of vertices may represent the set of facial tracking points. In some embodiments, the facial mesh includes a fixed number of vertices and polygonal faces. Certain vertices and faces in this mesh may be labeled as corresponding to particular facial features such as "tip of nose." "left edge of mouth," "inside left eye," and other suitable features. These features may be marked either manually or automatically in some or all of the key frame images.

In operation **1920**, the modeling component **250** deforms one or more portions of the facial mesh to fit the 3D model of the face. The modeling component **250** may deform the facial mesh by moving one or more vertices connecting two or more polygons of the set of polygons. The one or more vertices may be moved to correspond to a position of one or more facial tracking points of the set of facial tracking points within the volumetric 3D grid defined in the operation **1820**, described above.

In some embodiments, deformation of portions of the facial mesh may be performed by the modeling component **250** as an optimization. The deformation adjusts the positions of the vertices in the facial mesh subject to one or more constraints. For example, the surface of the facial mesh may be deformed such that the surface is within a predetermined proximity to the surface of the 3D model generated from the depth maps. In some instances, the facial mesh vertices (e.g., facial landmark representations) are deformed to project into the image frames for key frames proximate to facial tracking points (e.g., interest points) on the 3D model. The facial mesh may also be modified such that the overall shape of the face is preserved within the 3D model and the facial mesh. In some embodiments, the facial mesh includes a UV map. The UV map allows a texture map for the face to be constructed by projecting the image frames of the key frames onto the fitted facial mesh.

In some embodiments, after generation of the 3D model the model generation system **150** may transmit the 3D model to a data storage platform (e.g., the networked system **102**). The device used to capture the scan image data is associated with the end-user application, such as the mobile computing device (e.g., the client device **110**). The end-user application directs the model generation system **150** to transfer the 3D model data to the networked system **102** via the network **104**. The model generation system **150** may also retrieve 3D face model data from the networked system **102** for use by the end-user application on the client device **110**. In some instances, all of the data to generate the 3D model may also be transmitted, enabling the model reconstruction process to be performed at a future time or using more powerful computing equipment, computer architecture (such as, in a non-limiting example, within a cloud server or cloud network), or computing methodologies. The 3D model data may be optimized for transmission so as to minimize the transfer time through known encoding, optimization or other data transfer techniques that will not be further discussed herein. The data may be linked to one or more account identifiers associated with the end user **106** so as to be readily retrieved at a future time by the end user **106**, or an authorized third party on behalf of the end user **106**.

In some embodiments, the model generation system **150** may also retrieve the end user's 3D model data in order to populate the End-User Application. If the end user **106** installs the End-User Application on a second device distinct from the client device **110** used to capture one or more face models sent to the networked system **102**, the model generation system **150** may retrieve the identified model data. Upon retrieval of the model data, the model generation system **150** may cause presentation of the model retrieved or may have access to the face data to manipulate the retrieved face model on the second device.

In addition to 3D models, the model generation system **150** may generate 2.5 dimensional models. In some instances, the 2.5D models may be generated in combination with the 3D models of specified objects within a field of view. As shown in FIGS. **20** and **21**, the detection component **220** may detect object or points of interest within a scene in the field of view of the image capture device. The notification component **230** may generate user interface elements and instructions indicating movement of the client device **110** to enable capture of multiple angles of the scene. As shown, in some instances, the instructions indicate movement in a single direction. In some embodiments, the instructions indicate a movement in a plurality of directions.

The position component **240** may detect changes in position of the client device **110** with respect to one or more points of interest identified within the scene. The modeling component **250** may generate a 3D or 2.5D model of the scene. Where the modeling component **250** generates a 2.5D model, the 2.5D model may be a single depth map generated for the field of view. The operations described with respect to FIGS. **20** and **21** may be performed similarly to or the same as operations described with respect to an object of interest or a face, as described in the method **300** and the other methods described above.

In embodiments where a model for a scene is generated in conjunction with a 3D model for an object, the model for the scene may be generated simultaneously or separately from the 3D model for the object. For example, the instruction generated by the notification component **230** may instruct movement of the client device **110** in one or more directions while the object and the scene remain in a static position. In some embodiments, the model generation system **150** may identify and capture the object within the field of view, as described above, using movement of the image capture device in place of movement of the object. The model generation system **150** may then capture the scene. The model generation system **150** may then generate a 3D model for the object and a 2.5D model for the scene as a background to the object.

In some instances, the model generation system **150** identifies and captures the object within the field of view as described in the method **300** using movement of the object of interest. After capture of the object of interest, the notification component **230** may generate instructions for movement of the client device **110** and capture the scene. The model generation system **150** may then separately generate the 3D model for the object of interest and the 2.5D model for the scene in the background behind the object of interest.

According to various example embodiments, one or more of the methodologies described herein may facilitate generation and manipulation of 3D models based on a guided movement of a mobile computing device or image capture device. Methodologies for generating and modifying the 3D models automatically determine modeling parameters related to suitable movement of the object to capture and generate the 3D model. The methodologies further automatically generate instruction sets and user interface elements configured to guide and correct user interaction to ensure proper generation of 3D models. Accordingly, one or more of the methodologies described herein may have the effect of allowing a user to generate clear and accurate 3D models of objects, faces, and scenes without transmitting underlying modeling data to a third party modeling program or organization. Further, methodologies described herein may have the effect of reducing time, expense, and computing resources needed to generate 3D models. The methodologies described herein may also enable rendering and transmission of completed 3D models for direct integration into third party systems or products.

Components and Logic

Certain embodiments are described herein as including logic or a number of components or mechanisms. Components may constitute either software components (e.g., code embodied on a machine-readable medium) or hardware components. A "hardware component" is a tangible unit capable of performing certain operations and may be configured or arranged in a certain physical manner. In various example embodiments, one or more computer systems (e.g., a standalone computer system, a client computer system, or a server computer system) or one or more hardware components of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware component that operates to perform certain operations as described herein.

In some embodiments, a hardware component may be implemented mechanically, electronically, or any suitable combination thereof. For example, a hardware component may include dedicated circuitry or logic that is permanently configured to perform certain operations. For example, a hardware component may be a special-purpose processor, such as a Field-Programmable Gate Array (FPGA) or an Application Specific Integrated Circuit (ASIC). A hardware component may also include programmable logic or circuitry that is temporarily configured by software to perform certain operations. For example, a hardware component may include software executed by a general-purpose processor or other programmable processor. Once configured by such software, hardware components become specific machines (or specific components of a machine) uniquely tailored to perform the configured functions and are no longer general-purpose processors. It will be appreciated that the decision to implement a hardware component mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations.

Accordingly, the phrase "hardware component" should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein. As used herein, "hardware-implemented component" refers to a hardware component. Considering embodiments in which hardware components are temporarily configured (e.g., programmed), each of the hardware components need not be configured or instantiated at any one instance in time. For example, where a hardware component comprises a general-purpose processor configured by software to become a special-purpose processor, the general-purpose processor may be configured as respectively different special-purpose processors (e.g., comprising different hardware components) at different times. Software accordingly configures a particular processor or processors, for example, to constitute a particular hardware component at one instance of time and to constitute a different hardware component at a different instance of time.

Hardware components can provide information to, and receive information from, other hardware components. Accordingly, the described hardware components may be regarded as being communicatively coupled. Where multiple hardware components exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) between or among two or more of the hardware components. In embodiments in which multiple hardware components are configured or instantiated at different times, communications between such hardware components may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple hardware components have access. For example, one hardware component may perform an operation and store the output of that operation in a memory device to which it is communicatively coupled. A further hardware component may then, at a later time, access the memory device to retrieve and process the stored output. Hardware components may also initiate communications with input or output devices, and can operate on a resource (e.g., a collection of information).

The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented components that operate to perform one or more operations or functions described herein. As used herein, "processor-implemented component" refers to a hardware component implemented using one or more processors.

Similarly, the methods described herein may be at least partially processor-implemented, with a particular processor or processors being an example of hardware. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented components. Moreover, the one or more processors may also operate to support performance of the relevant operations in a "cloud computing" environment or as a "software as a service" (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), with these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., an API).

The performance of certain of the operations may be distributed among the processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the processors or processor-implemented components may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the processors or processor-implemented components may be distributed across a number of geographic locations.

Machine and Software Architecture

The components, methods, applications and so forth described in conjunction with FIGS. **2-21** are implemented in some embodiments in the context of a machine and an associated software architecture. In various embodiments, the components, methods, applications and so forth described above are implemented in the context of a plurality of machines, distributed across and communicating via a network, and one or more associated software architectures. The sections below describe representative software architecture(s) and machine (e.g., hardware) architecture that are suitable for use with the disclosed embodiments.

Software architectures are used in conjunction with hardware architectures to create devices and machines tailored to particular purposes. For example, a particular hardware architecture coupled with a particular software architecture will create a mobile device, such as a mobile phone, tablet device, or so forth. A slightly different hardware and software architecture may yield a smart device for use in the "internet of things," while yet another combination produces a server computer for use within a cloud computing architecture. Not all combinations of such software and hardware architectures are presented here as those of skill in the art can readily understand how to implement the present embodiments in different contexts from the disclosure contained herein.

Software Architecture

FIG. **22** is a block diagram **2200** illustrating a representative software architecture **2202**, which may be used in conjunction with various hardware architectures herein described. FIG. **22** is merely a non-limiting example of a software architecture and it will be appreciated that many other architectures may be implemented to facilitate the functionality described herein. The software architecture **2202** may be executing on hardware such as machine **2300** of FIG. **23** that includes, among other things, processors **2310**, memory **2330**, and Input/Output (I/O) components **2350**. A representative hardware layer **2204** is illustrated and can represent, for example, the machine represented by the block diagram **2200** of FIG. **22**. The representative hardware layer **2204** comprises one or more processing units **2206** having associated executable instructions **2208**. Executable instructions **2208** represent the executable instructions of the software architecture **2202**, including implementation of the methods, components, and so forth of FIGS. **2-21**. Hardware layer **2204** also includes memory and/or storage components **2210**, which also have executable instructions **2208**. Hardware layer **2204** may also comprise other hardware as indicated by **2212**, which represents any other hardware of the hardware layer **2204**, such as the other hardware illustrated as part of machine **2300**.

In the example architecture of FIG. **22**, the software architecture **2202** may be conceptualized as a stack of layers where each layer provides particular functionality. For example, the software architecture **2202** may include layers such as an operating system **2214**, libraries **2216**, frameworks/middleware **2218**, applications **2220**, and presentation layer **2244**. Operationally, the applications **2220** and/or other components within the layers may invoke API calls **2224** through the software stack and receive a response, returned values, and so forth, illustrated as messages **2226** in response to the API calls **2224**. The layers illustrated are representative in nature and not all software architectures have all layers. For example, some mobile or special purpose operating systems may not provide a frameworks/middleware layer **2218**, while others may provide such a layer. Other software architectures may include additional or different layers.

The operating system **2214** may manage hardware resources and provide common services. The operating system **2214** may include, for example, a kernel **2228**, services **2230**, and drivers **2232**. The kernel **2228** may act as an abstraction layer between the hardware and the other software layers. For example, the kernel **2228** may be responsible for memory management, processor management (e.g., scheduling), component management, networking, security settings, and so on. The services **2230** may provide other common services for the other software layers. The drivers **2232** may be responsible for controlling or interfacing with the underlying hardware. For instance, the drivers **2232** may include display drivers, camera drivers, Bluetooth® drivers, flash memory drivers, serial communication drivers (e.g., Universal Serial Bus (USB) drivers), Wi-Fi® drivers, audio drivers, power management drivers, and so forth depending on the hardware configuration.

The libraries **2216** may provide a common infrastructure that may be utilized by the applications **2220** and/or other components and/or layers. The libraries **2216** typically provide functionality that allows other software components to perform tasks in an easier fashion than to interface directly with the underlying operating system **2214** functionality (e.g., kernel **2228**, services **2230** and/or drivers **2232**). The libraries **2216** may include system **2234** libraries (e.g., C standard library) that may provide functions such as memory allocation functions, string manipulation functions, mathematic functions, and the like. In addition, the libraries **2216** may include API libraries **2236** such as media libraries (e.g., libraries to support presentation and manipulation of various media format such as Moving Pictures Experts Group 4 (MPEG4), H.264, MP3, Advanced Audio Coding (AAC), Adaptive Multi-Rate (AMR), Joint Photographic Experts Group (JPEG). Portable Network Graphics (PNG)), graphics libraries (e.g., an OpenGL framework that may be used to render two dimensions and three dimensions in a graphic content on a display), database libraries (e.g., SQLite that may provide various relational database functions), web libraries (e.g., WebKit that may provide web browsing functionality), and the like. The libraries **2216** may also include a wide variety of other libraries **2238** to provide many other APIs to the applications **2220** and other software components.

The frameworks **2218** (also sometimes referred to as middleware) may provide a higher-level common infrastructure that may be utilized by the applications **2220** and/or other software components. For example, the frameworks **2218** may provide various graphical user interface functions, high-level resource management, high-level location services, and so forth. The frameworks **2218** may provide a broad spectrum of other APIs that may be utilized by the applications **2220** and/or other software components, some of which may be specific to a particular operating system or platform. In some example embodiments, model generation components **2219** (e.g., one or more components of the model generation system **150**) may be implemented at least in part within the middleware/frameworks **2218**. For example, in some instances, at least a portion of the presentation component **210**, providing graphical and non-graphical user interface functions, may be implemented in the middleware/frameworks **2218**. Similarly, in some example embodiments, portions of one or more of the presentation component **210**, the notification component **230**, the modeling component **250**, and the model review component **260** may be implemented in the middleware/frameworks **2218**.

The applications **2220** include built-in applications **2240**, third party applications **2242**, and/or model generation components **2243** (e.g., user facing portions of one or more of the components of the model generation system **150**). Examples of representative built-in applications **2240** may include, but are not limited to, a contacts application, a browser application, a book reader application, a location application, a media application, a messaging application, and/or a game application. Third party applications **2242** may include any of the built in applications as well as a broad assortment of other applications. In a specific example, the third party application **2242** (e.g., an application developed using the Android™ or iOS™ software development kit (SDK) by an entity other than the vendor of the particular platform) may be mobile software running on a mobile operating system such as iOS™, Android™, Windows® Phone, or other mobile operating systems. In this example, the third party application **2242** may invoke the API calls **2224** provided by the mobile operating system such as operating system **2214** to facilitate functionality described herein. In various example embodiments, the user facing portions of the model generation components **2243** may include one or more components or portions of components described with respect to FIG. **2**. For example, in some instances, portions of the presentation component **210**, the detection component **220**, the notification component **230**, the position component **240**, the modeling component **250**, and the model review component **260** associated with user interface elements (e.g., data entry and data output functions) may be implemented in the form of an application.

The applications **2220** may utilize built in operating system functions (e.g., kernel **2228**, services **2230** and/or drivers **2232**), libraries (e.g., system **2234**. APIs **2236**, and other libraries **2238**), frameworks/middleware **2218** to create user interfaces to interact with users of the system. Alternatively. or additionally, in some systems interactions with a user may occur through a presentation layer, such as presentation layer **2244**. In these systems, the application/component "logic" can be separated from the aspects of the application/component that interact with a user.

Some software architectures utilize virtual machines. In the example of FIG. **22**, this is illustrated by virtual machine **2248**. A virtual machine creates a software environment where applications/components can execute as if they were executing on a hardware machine (such as the machine of FIG. **23**, for example). A virtual machine is hosted by a host operating system (operating system **2214** in FIG. **22**) and typically, although not always, has a virtual machine monitor **2246**, which manages the operation of the virtual machine as well as the interface with the host operating system (i.e., operating system **2214**). A software architecture executes within the virtual machine such as an operating system **2250**, libraries **2252**, frameworks/middleware **2254**, applications **2256** and/or presentation layer **2258**. These layers of software architecture executing within the virtual machine **2248** can be the same as corresponding layers previously described or may be different.

Example Machine Architecture and Machine-Readable Medium

FIG. **23** is a block diagram illustrating components of a machine **2300**, according to some example embodiments, able to read instructions (e.g., processor executable instructions) from a machine-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically. FIG. **23** shows a diagrammatic representation of the machine **2300** in the example form of a computer system, within which instructions **2316** (e.g., software, a program, an application, an applet, an app, or other executable code) for causing the machine **2300** to perform any one or more of the methodologies discussed herein may be executed. For example the instructions may cause the machine to execute the flow diagrams of FIGS. **3** and **16-19**. Additionally, or alternatively, the instructions may implement the presentation component **210**, the detection component **220**, the notification component **230**, the position component **240**, the modeling component **250**, and the model review component **260** of FIGS. **2-21**, and so forth. The instructions transform the general, non-programmed machine into a particular machine programmed to carry out the described and illustrated functions in the manner described.

In alternative embodiments, the machine **2300** operates as a standalone device or may be coupled (e.g., networked) to other machines in a networked system. In a networked deployment, the machine **2300** may operate in the capacity of a server machine or a client machine in a server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. The machine **2300** may comprise, but not be limited to, a server computer, a client computer, a personal computer (PC), a tablet computer, a laptop computer, a netbook, a set-top box, an entertainment media system, a web appliance, a network router, a network switch, a network bridge, or any machine capable of executing the instructions **2316**, sequentially or otherwise, that specify actions to be taken by machine **2300**. In some example embodiments, in the networked deployment, one or more machines may implement at least a portion of the components described above. The one or more machines interacting with the machine **2300** may comprise, but not be limited to a PDA, an entertainment media system, a cellular telephone, a smart phone, a mobile device, a wearable device (e.g., a smart watch), a smart home device (e.g., a smart appliance), and other smart devices. Further, while only a single machine **2300** is illustrated, the term "machine" shall also be taken to include a collection of machines **2300** that individually or jointly execute the instructions **2316** to perform any one or more of the methodologies discussed herein.

The machine **2300** may include processors **2310**, memory **2330**, and I/O components **2350**, which may be configured to communicate with each other such as via a bus **2302**. In an example embodiment, the processors **2310** (e.g., a Central Processing Unit (CPU), a Reduced Instruction Set Computing (RISC) processor, a Complex Instruction Set Computing (CISC) processor, a GPU, a Digital Signal Processor (DSP), an ASIC, a Radio-Frequency Integrated Circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, processor **2312** and processor **2314** that may execute instructions **2316**. The term "processor" is intended to include multi-core processor that may comprise two or more independent processors (sometimes referred to as "cores") that may execute instructions contemporaneously. Although FIG. **23** shows multiple processors, the machine **2300** may include a single processor with a single core, a single processor with multiple cores (e.g., a multi-core process), multiple processors with a single core, multiple processors with multiples cores, or any combination thereof.

The memory/storage **2330** may include a memory **2332**, such as a main memory, or other memory storage, and a storage unit **2336**, both accessible to the processors **2310** such as via the bus **2302**. The storage unit **2336** and memory **2332** store the instructions **2316** embodying any one or more of the methodologies or functions described herein. The instructions **2316** may also reside, completely or partially, within the memory **2332**, within the storage unit **2336**, within at least one of the processors **2310** (e.g., within the processor's cache memory), or any suitable combination thereof, during execution thereof by the machine **2300**. Accordingly, the memory **2332**, the storage unit **2336**, and the memory of processors **2310** are examples of machine-readable media.

As used herein, "machine-readable medium" means a device able to store instructions and data temporarily or permanently and may include, but is not be limited to, random-access memory (RAM), read-only memory (ROM), buffer memory, flash memory, optical media, magnetic media, cache memory, other types of storage (e.g., Erasable Programmable Read-Only Memory (EEPROM)) and/or any suitable combination thereof. The term "machine-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) able to store instructions **2316**. The term "machine-readable medium" shall also be taken to include any medium, or combination of multiple media, that is capable of storing instructions (e.g., instructions **2316**) for execution by a machine (e.g., machine **2300**), such that the instructions, when executed by one or more processors of the machine **2300** (e.g., processors **2310**), cause the machine **2300** to perform any one or more of the methodologies described herein. Accordingly, a "machine-readable medium" refers to a single storage apparatus or device, as well as "cloud-based" storage systems or storage networks that include multiple storage apparatus or devices. The term "machine-readable medium" excludes signals per se.

The I/O components **2350** may include a wide variety of components to receive input, provide output, produce output, transmit information, exchange information, capture measurements, and so on. The specific I/O components **2350** that are included in a particular machine will depend on the type of machine. For example, portable machines such as mobile phones will likely include a touch input device or other such input mechanisms, while a headless server machine will likely not include such a touch input device. It will be appreciated that the I/O components **2350** may include many other components that are not shown in FIG. **23**. The I/O components **2350** are grouped according to functionality merely for simplifying the following discussion and the grouping is in no way limiting. In various example embodiments, the I/O components **2350** may include output components **2352** and input components **2354**. The output components **2352** may include visual components (e.g., a display such as a plasma display panel (PDP), a light emitting diode (LED) display, a liquid crystal display (LCD), a projector, or a cathode ray tube (CRT)), acoustic components (e.g., speakers), haptic components (e.g., a vibratory motor, resistance mechanisms), other signal generators, and so forth. The input components **2354** may include alphanumeric input components (e.g., a keyboard, a touch screen configured to receive alphanumeric input, a photo-optical keyboard, or other alphanumeric input components), point based input components (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instrument), tactile input components (e.g., a physical button, a touch screen that provides location and/or force of touches or touch gestures, or other tactile input components), audio input components (e.g., a microphone), and the like.

In further example embodiments, the I/O components **2350** may include biometric components **2356**, motion components **2358**, environmental components **2360**, or position components **2362** among a wide array of other components. For example, the biometric components **2356** may include components to detect expressions (e.g., hand expressions, facial expressions, vocal expressions, body gestures, or eye tracking), measure biosignals (e.g., blood pressure, heart rate, body temperature, perspiration, or brain waves), identify a person (e.g., voice identification, retinal identification, facial identification, fingerprint identification, or electroencephalogram based identification), and the like. The motion components **2358** may include acceleration sensor components (e.g., accelerometer), gravitation sensor components, rotation sensor components (e.g., gyroscope), and so forth. The environmental components **2360** may include, for example, illumination sensor components (e.g., photometer), temperature sensor components (e.g., one or more thermometers that detect ambient temperature), humidity sensor components, pressure sensor components (e.g., barometer), acoustic sensor components (e.g., one or more microphones that detect background noise), proximity sensor components (e.g., infrared sensors that detect nearby objects), gas sensors (e.g., gas detect sensors to detection concentrations of hazardous gases for safety or to measure pollutants in the atmosphere), or other components that may provide indications, measurements, or signals corresponding to a surrounding physical environment. The position components **2362** may include location sensor components (e.g., a GPS receiver component), altitude sensor components (e.g., altimeters or barometers that detect air pressure from which altitude may be derived), orientation sensor components (e.g., magnetometers), and the like.

Communication may be implemented using a wide variety of technologies. The I/O components **2350** may include communication components **2364** operable to couple the machine **2300** to a network **2380** or devices **2370** via coupling **2382** and coupling **2372**, respectively. For example, the communication components **2364** may include a network interface component or other suitable device to interface with the network **2380**. In further examples, communication components **2364** may include wired communication components, wireless communication components, cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy). Wi-Fi® components, and other communication components to provide communication via other modalities. The devices **2370** may be another machine or any of a wide variety of peripheral devices (e.g., a peripheral device coupled via a USB).

Moreover, the communication components **2364** may detect identifiers or include components operable to detect identifiers. For example, the communication components **2364** may include Radio Frequency Identification (RFID) tag reader components, NFC smart tag detection components, optical reader components (e.g., an optical sensor to detect one-dimensional bar codes such as Universal Product Code (UPC) bar code, multi-dimensional bar codes such as Quick Response (QR) code. Aztec code. Data Matrix, Dataglyph, MaxiCode. PDF417, Ultra Code, UCC RSS-2D bar code, and other optical codes), or acoustic detection components (e.g., microphones to identify tagged audio signals). In addition, a variety of information may be derived via the communication components **2364**, such as, location via Internet Protocol (IP) geo-location, location via Wi-Fi® signal triangulation, location via detecting a NFC beacon signal that may indicate a particular location, and so forth.

Transmission Medium

In various example embodiments, one or more portions of the network **2380** may be an ad hoc network, an intranet, an extranet, a VPN, a LAN, a WLAN, a WAN, a WWAN, a MAN, the Internet, a portion of the Internet, a portion of the PSTN, a plain old telephone service (POTS) network, a cellular telephone network, a wireless network, a Wi-Fi® network, another type of network, or a combination of two or more such networks. For example, the network **2380** or a portion of the network **2380** may include a wireless or cellular network and the coupling **2382** may be a Code Division Multiple Access (CDMA) connection, a Global System for Mobile communications (GSM) connection, or other type of cellular or wireless coupling. In this example, the coupling **2382** may implement any of a variety of types of data transfer technology, such as Single Carrier Radio Transmission Technology (1×RTT), Evolution-Data Optimized (EVDO) technology, General Packet Radio Service (GPRS) technology. Enhanced Data rates for GSM Evolution (EDGE) technology, third Generation Partnership Project (3GPP) including 3G, fourth generation wireless (4G) networks, Universal Mobile Telecommunications System (UMTS), High Speed Packet Access (HSPA), Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) standard, others defined by various standard setting organizations, other long range protocols, or other data transfer technology.

The instructions **2316** may be transmitted or received over the network **2380** using a transmission medium via a network interface device (e.g., a network interface component included in the communication components **2364**) and utilizing any one of a number of well-known transfer protocols (e.g., hypertext transfer protocol (HTTP)). Similarly, the instructions **2316** may be transmitted or received using a transmission medium via the coupling **2372** (e.g., a peer-to-peer coupling) to devices **2370**. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding, or carrying instructions **2316** for execution by the machine **2300**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

Language

Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

Although an overview of the inventive subject matter has been described with reference to specific example embodiments, various modifications and changes may be made to these embodiments without departing from the broader scope of embodiments of the present disclosure. Such embodiments of the inventive subject matter may be referred to herein, individually or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single disclosure or inventive concept if more than one is, in fact, disclosed.

The embodiments illustrated herein are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed. Other embodiments may be used and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. The Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

As used herein, the term "or" may be construed in either an inclusive or exclusive sense. Moreover, plural instances may be provided for resources, operations, or structures described herein as a single instance. Additionally, boundaries between various resources, operations, components, engines, and data stores are somewhat arbitrary, and particular operations are illustrated in a context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within a scope of various embodiments of the present disclosure. In general, structures and functionality presented as separate resources in the example configurations may be implemented as a combined structure or resource. Similarly, structures and functionality presented as a single resource may be implemented as separate resources. These and other variations, modifications, additions, and improvements fall within a scope of embodiments of the present disclosure as represented by the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A method, comprising:

detecting, by one or more processors coupled to a display device, an object within a field of view of an image capture device of a mobile computing device;

displaying a movement element and a position indicator in a graphical user interface together with an image of the object that is within the field of view of the image capture device, the movement element including one or more visual movement instructions for positioning the object within the field of view of the image capture device;

accessing motion data representing motion of the object;

continuously changing a size of the position indicator by an amount determined based on a current position of the object within the field of view and a distance of travel detected for the object based on the motion data representing motion of the object, the position indicator comprising a line with a graphical element that moves along the line from a start position towards an end position of the line, the line being reduced in size as the graphical element moves from the start position to the end position; and

generating, by the display device, a three-dimensional model of the object based on key frames that are identified based on the distance of travel detected for the object.

2. The method of claim **1**, wherein a location of the position indicator is proportional to an amount of motion detected in the object, and wherein a predetermined number of the key frames are identified by equally dividing a distance between an initial position and a final position of a portion of the object, further comprising:

identifying, within the predetermined number of key frames, first and second key frames corresponding respectively to first and second position changes of the object within the field of view of the image capture device relative to a starting position;

generating first and second depth maps having respectively first and second resolutions, the first depth map being generated based on the first key frame and the second depth map being generated based on the second key frame; and

generating the three-dimensional model based further on the first and second depth maps.

3. The method of claim **2**, wherein the object comprises a face, further comprising:

identifying a set of facial tracking points on the face;

in response to detecting one or more of the first and second position changes, generating graphical representations of the set of facial tracking points on the face within the graphical user interface; and

causing presentation of the graphical representations of the set of facial tracking points on the face for a duration of detecting the first and second position changes.

4. The method of claim **2**, wherein the first position change is an expected position change having a first initial position and a first final position, and wherein the first position change has a first set of intermediate positions, the first initial position, the first set of intermediate positions, and the first final position being associated with a first side of the object.

5. The method of claim 4, wherein the second position change is an expected position change having a second initial position and a second final position, and wherein the second position change has a second set of intermediate positions, the second initial position, the second set of intermediate positions, and the second final position being associated with a second side of the object opposite the first side of the object.

6. The method of claim 1, further comprising:

identifying a set of tracking points on the object within the field of view of the image capture device;

identifying a first key frame of the key frames where the set of tracking points have a set of first positions;

determining a change in position of one or more tracking points of the set of tracking points from the set of first positions; and

based on the change in position, identifying a second key frame of the set of key frames where the one or more tracking points have a second position.

7. The method of claim 6, wherein determining the change in position of the one or more tracking points comprises:

in response to initiation of the change in position of the one or more tracking points, identifying a trajectory for each of the one or more tracking points;

determining an average length of the trajectories of the one or more tracking points; and

determining the average length exceeds a trajectory threshold.

8. The method of claim 7, wherein the second key frame is identified based on determining the average length exceeds the trajectory threshold.

9. The method of claim 7, further comprising:

identifying one or more subsequent key frames based on one or more changes in position of the one or more tracking points along the trajectories; and

based on the first key frame, the second key frame, and the one or more subsequent key frames, generating a set of relative position estimates for the mobile computing device with respect to the object, a relative position estimate of the set of relative position estimates being generated for each key frame.

10. The method of claim 9, further comprising:

based on the first key frame, the second key frame, the one or more subsequent key frames, and the set of relative position estimates, generating a set of depth maps including a depth map for each key frame.

11. The method of claim 10, further comprising:

fusing the set of depth maps to generate the three-dimensional model of the object;

defining a volumetric three-dimensional grid for the three-dimensional model of the object; and

representing a three-dimensional surface of the three-dimensional model.

12. The method of claim 1, wherein the movement element overlays the image of the object, and wherein the movement element comprises a focus element and a pose element.

13. The method of claim 1, wherein reducing a size of the line comprises shortening a length of the line.

14. A system, comprising:

one or more processors;

an image capture device operative coupled to the one or more processors; and

a non-transitory processor-readable storage medium storing processor executable instructions that, when executed by the one or more processors, causes the one or more processors to perform operations comprising:

detecting an object within a field of view of an image capture device of a mobile computing device;

displaying a movement element and a position indicator in a graphical user interface together with an image of the object that is within the field of view of the image capture device, the movement element including one or more visual movement instructions for positioning the object within the field of view of the image capture device;

accessing motion data representing motion of the object;

continuously changing a size of the position indicator by an amount determined based on a current position of the object within the field of view and a distance of travel detected for the object based on the motion data representing motion of the object, the position indicator comprising a line with a graphical element that moves along the line from a start position towards an end position of the line, the line being reduced in size as the graphical element moves from the start position to the end position; and

generating a three-dimensional model of the object based on key frames that are identified based on the distance of travel detected for the object.

15. The system of claim 14, wherein a location of the position indicator is proportional to an amount of motion detected in the object, and wherein a predetermined number of the key frames are identified by equally dividing a distance between an initial position and a final position of a portion of the object, the operations further comprising:

identifying, within the predetermined number of key frames, first and second key frames corresponding respectively to first and second position changes of the object within the field of view of the image capture device relative to a starting position;

generating first and second depth maps having respectively first and second resolutions, the first depth map being generated based on the first key frame and the second depth map being generated based on the second key frame; and

generating the three-dimensional model based further on the first and second depth maps.

16. The system of claim 15, wherein the object comprises a face, the operations further comprising:

identifying a set of facial tracking points on the face;

in response to detecting one or more of the first and second position changes, generating graphical representations of the set of facial tracking points on the face within the graphical user interface; and

causing presentation of the graphical representations of the set of facial tracking points on the face for a duration of detecting the first and second position changes.

17. The system of claim 15, wherein the first position change is an expected position change having a first initial position and a first final position, and wherein the first position change has a first set of intermediate positions, the first initial position, the first set of intermediate positions, and the first final position being associated with a first side of the object.

18. The system of claim 17, wherein the second position change is an expected position change having a second initial position and a second final position, and wherein the second position change has a second set of intermediate positions, the second initial position, the second set of intermediate positions, and the second final position being associated with a second side of the object opposite the first side of the object.

19. A non-transitory processor-readable storage medium storing processor executable instructions that, when executed by one or more processors, causes the one or more processors to perform operations comprising:

detecting an object within a field of view of an image capture device of a mobile computing device;

displaying a movement element and a position indicator in a graphical user interface together with an image of the object that is within the field of view of the image capture device, the movement element including one or more visual movement instructions for positioning the object within the field of view of the image capture device;

accessing motion data representing motion of the object;

continuously changing a size of the position indicator by an amount determined based on a current position of the object within the field of view and a distance of travel detected for the object based on the motion data representing motion of the object, the position indicator comprising a line with a graphical element that moves along the line from a start position towards an end position of the line, the line being reduced in size as the graphical element moves from the start position to the end position; and

generating a three-dimensional model of the object based on key frames that are identified based on the distance of travel detected for the object.

20. The non-transitory processor-readable storage medium of claim 19, wherein a location of the position indicator is proportional to an amount of motion detected in the object, and wherein a predetermined number of the key frames are identified by equally dividing a distance between an initial position and a final position of a portion of the object, the operations further comprising:

identifying, within the predetermined number of key frames, first and second key frames corresponding respectively to first and second position changes of the object within the field of view of the image capture device relative to a starting position;

generating first and second depth maps having respectively first and second resolutions, the first depth map being generated based on the first key frame and the second depth map being generated based on the second key frame; and

generating the three-dimensional model based further on the first and second depth maps.

* * * * *